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REVIEW OF ENGINEERING PROGRESS ABROAD

VOL. III. No. 7 JULY, 1942

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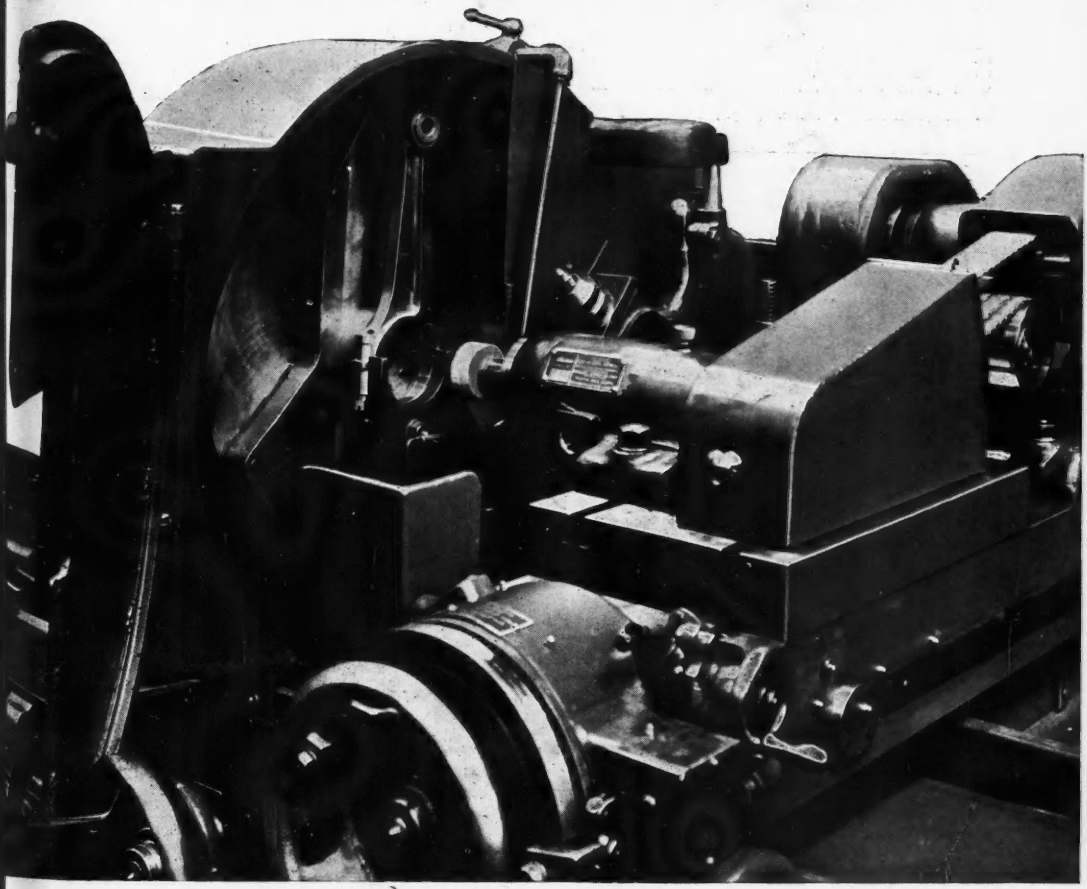

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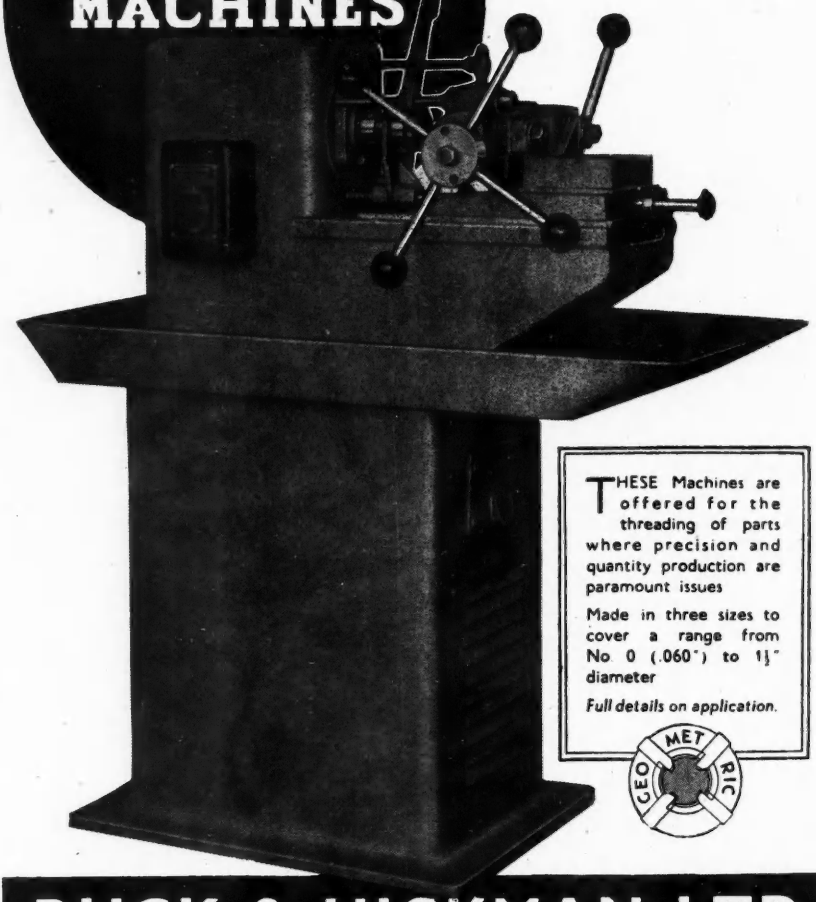

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BOLTED JOINTS, PRESENT POSITION OF TECHNIQUE

By DIPL. ING. L. MARTINAGLIA. (From *Schweizerische Bauzeitung*, Vol. 119, Nos. 10 and 11, March, 1942, pp. 107-112 and 122-126).

VERY important and certainly the most frequently employed machine elements are screws, bolts and nuts and kindred. The appropriate design of bolts and nuts, etc., the problems connected with their application, and their behaviour in use are, however, not well enough known by many an engineer. The reason for this is the complicated nature of internal structure of bolted joints which makes accurate estimation of the actual forces acting therein almost impossible.

Resent research work has contributed greatly to the clarification of problems connected with bolted joint design and as a result far reaching improvements were achieved. As the technical literature related to this subject is widely spread, it is the aim of the author to collect and give account of the technical development in this field.

1. Some Principal Facts.

11. *Flow of forces.*—In a bolted joint, the flow of forces in the bolt shank and the nut is turned round by 180°. This sharp change of direction produces a concentration of forces (high stress) in the first two loaded screw threads, Fig. 1.

12. *Distribution of force in threads.*—Calculations have shown that under normal loading conditions a nut having 6 turns carries up to 75% of the total load in the first two threads in engagement (Fig. 2), varying slightly with the type of thread. This proportion increases with stiffness, and the maximum, i.e., 75%, is reached in square threads, while in Whitworth or other types of thread the load distribution is more favourable.

13. *Load distribution in the core.*—At the root of the threads a stress concentration is produced. If σ_n is the calculated mean stress in the core, and σ_{max}. the peak value of the stress at the root, then $\frac{\sigma_{max}}{\sigma_n} = \alpha_k$ is a form factor which has a value of about 8 for Whitworth thread with sharp cornered roots (Fig. 3).

14. *Weakest sections in standard Bolts and Nuts.*—Mass examination has revealed that there are three weak sections in nuts and bolts, Fig. 4. These are: At the first loaded thread, at the end of thread, and, at the section where the shaft changes dimensions to form the bolt head. These sections are characterised by a strong concentration of lines of forces (Fig. 5). The aim of bolt design is, therefore, to give additional strength to these sections.

2. Effect of Loading.

21. *Tensile load.*—Consider the case of two flanges bolted together, as shown in Fig. 6. When the nut is tightened, the bolt is stressed by V kg and the shaft stretches by λ_v cm. At the same time the two flanges

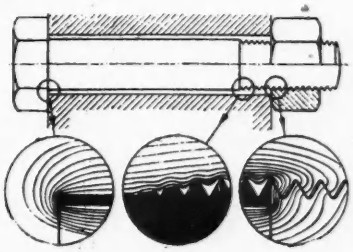


Fig. 5

are compressed by an amount δ_v cm. The forces acting are:

in the bolt, $V = c_1 . \lambda_v$ (kg)
in the flanges, $V = c_2 . \delta_v$ (kg)

where c_1 is the stiffness of the bolt and c_2 that of the flanges; the dimensions of stiffness being, of course, M/L=kg/cm. If now a working load of P kg is applied to the bolted joint, this will cause an additional elongation, λ_z cm. in the bolt shaft, so that the total stretch becomes $\lambda_v + \lambda_z$ cm. During this elongation of the bolt, the flanges are permitted to expand by the same amount, and the compression of the flanges becomes now $\delta_v - \delta_z$. This means that part of the original stress in the bolt (caused by the compression of the flanges) is relieved and the total load acting on it is not P+V, but less than that. In other words only a portion, Pz, of P constitutes an additional loading in the bolt. Thus

$$V + P_z = c_1 (\lambda_v + \lambda_z) \text{ kg.}$$

The value of Pz is dependent upon the stiffness of the bolt.

Since Hook's law applies to this type of stressing (being within the elastic limit), the deformation of the bolt under the action of force P+V is as shown in Fig. 7.

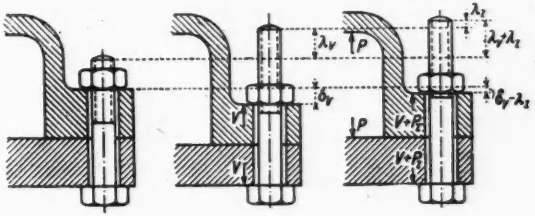


Fig. 6

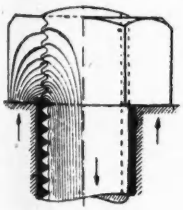


Fig. 1

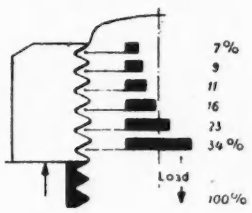


Fig. 2

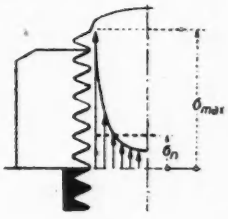


Fig. 3

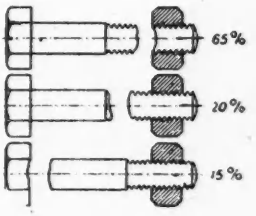


Fig. 4

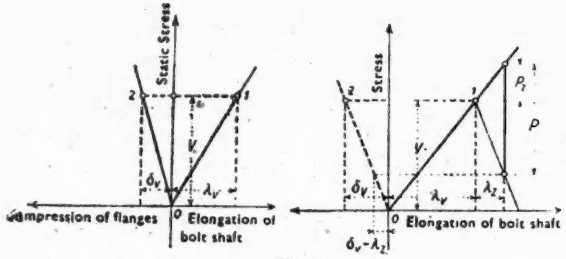


Fig. 7

As will be seen later, only the load Pz is relevant for the endurance strength of the bolt, since this load is fluctuating, while the stress due to V is static.

22. *Torsion.*—The turning moment applied to the spanner during tightening the nut is used up partly in stretching the bolt shaft by λ_v, partly in overcoming the frictional resistance of the threads, and in overcoming the friction of the bearing surface of the nut. The frictional resistance of the threads causes a permanent twist, τ, in the bolt shank and hence a stress. An average value of τ (for Whitworth thread) is given by

$$\frac{\tau_v}{\sigma_{nv}} = 0.5$$

where σ_{nv} is the nominal stress due to V. Consideration must be given, therefore, to an additional 50% of the tensile stress due to the permanent twist. The value of τ_v can be slightly reduced by adequate lubrication.

Measurements have shown that the effect of twisting is to reduce the yield stress by about 25%, and therefore, the total stress in the shaft due to V and P must not exceed 75% of the yield stress of the bolt.

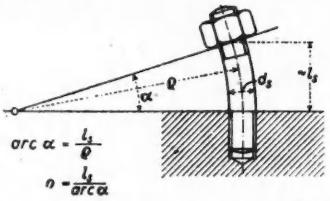


Fig. 8

23. *Bending.*—Frequently, the working load sets up a bending moment in the bolt, Fig. 8, which can be calculated from M_b. $\rho = EI$, where $\rho = l_s/\alpha$, and from Fig. 8

$$W_b \sigma_b \frac{l_s}{\alpha} = EI, \text{ and}$$

$$\sigma_b = E \frac{d_s}{2} \frac{\alpha}{l_s}$$

The value of σ_b calculated from this expression is too high because it does not allow for the play of the bolt in the flanges and the slight deformation of the nut and threaded portion of the bolt shaft; but it is sufficiently accurate for purposes of comparing stresses in various bolts. The equation also shows that σ_b can be reduced by: 1./ reducing the bolt shaft diameter, 2./ using longer bolts and 3./ arranging a rigid construction so as to keep α small.

3. How to Increase the Endurance Strength of Bolts.

31. *Type of thread.* Fig. 9 shows the advantage of using a large radius of curvature at the thread roots, especially when the load is impacting. For particularly important joints abnormally large radius of curvature is used for safety (Fig. 10).

32. *Bolt head.* From a similar consideration the radius of curvature at the head-shaft transition should be also as large as possible. With standard bolts this is not always feasible, but bolts with turned down shaft (" elastic bolts ") permit a much larger radius of curvature. It is essential to give a clean finish to the curvature not to impair the effect of large curvature by a rough surface.

33. *Length of threaded part.* With impact or oscillating loads, the endurance strength of bolts can be considerably increased by making the threaded part longer. The free threaded part (Fig. 12) is, namely, more elastic than the full section.

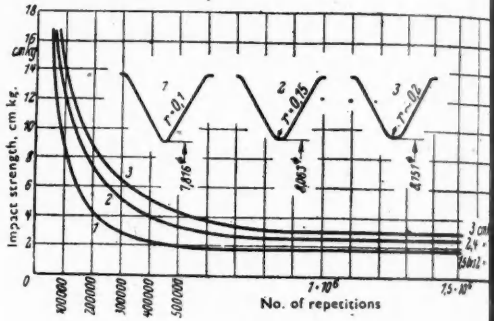


Fig. 9

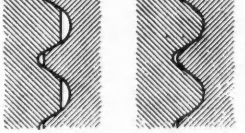


Fig. 10

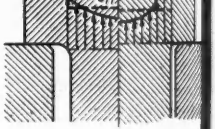


Fig. 11

(In Fig. 11, Left half: Elastic bolt; Right half, Standard bo

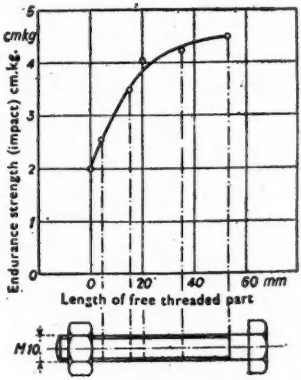
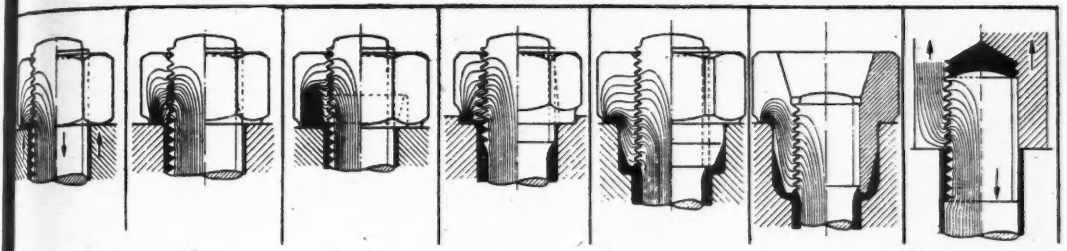


Fig. 12

Fig. 13 Fig. 14 Fig. 15 Fig. 16 Fig. 17 Fig. 18 Fig. 19



Fluctuating load ± 4.8 ± 5.2 $\sigma_w^{\kappa} = \pm 7.8$ kg/mm²

$\sigma_w^{\kappa} = \pm 4.0$ kg/mm²

34. *Design of nut.* Favourable construction will reduce the proportion of load carried by the first loaded thread of the nut. The aim of improved designs is to achieve a more uniform load distribution. Some solutions are shown in Figs. 14-19. Fig. 14 shows a nut with a bevelled entrance which prevents heavy load being carried by the first thread. Measurements give the increase in endurance strength for such nuts as 20%. Fig. 15 shows a nut with a groove cut at the lower side. Here the improvement claimed is about 30%. Fig. 16 shows a nut with relief ground threading so that the bending strength of the individual thread turns, in respect of the bearing surfaces, decreases steadily. A uniform load distribution is thus achieved. This solution is, however, applicable only to very large bolts and nuts and is complicated to manufacture. Still other solutions are shown in Figs. 17 and 18, both of which tend to improve upon the sudden change of direction of the lines of forces and provide a more uniform pattern.

35. *Material of bolt nut.* Much depends also upon the material of which the nut is made. As a general guidance a small modulus of elasticity is preferential as the stiffness in bending is thereby reduced. As an example cast iron and light alloy nuts give better results than those made of steel. The disadvantage of cast iron nuts being the larger dimensions necessary.

36. *Studs.* The corresponding deformation of the stud and the threaded bushing, and the smaller change of direction of the lines of forces gives a greater endurance strength to studs than is inherent to bolts and nuts. The amplitude of the fluctuating working load is about 90% greater for a $\frac{3}{4}$" stud than for a bolt and nut of corresponding dimensions.

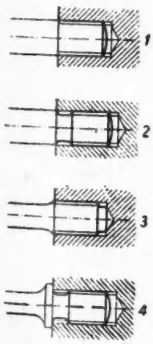


Fig. 20

37. *Stud design.*—To strengthen the weak sections of studs, Fig. 20 shows some methods of improvement.

(1) Standard stud: High peak stress in first turn of thread.

(2) Better than 1, first stressed thread dislocated from weak section.

(3) Better than 1 and 2. First stressed thread partially relieved as stud end is supported. Turned down shaft relieves high bending stress.

(4) Best but most expensive solution: Stud supported by collar reduces stress due to bending in threaded part.

It is advisable to turn down the shaft at the end of thread by about 0.2 to 0.3 mm. below the core section over a length of not less than 0.5d. (Fig. 21). This simple method increases the endurance strength of a stud especially if it has to resist also a bending moment.

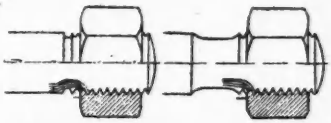
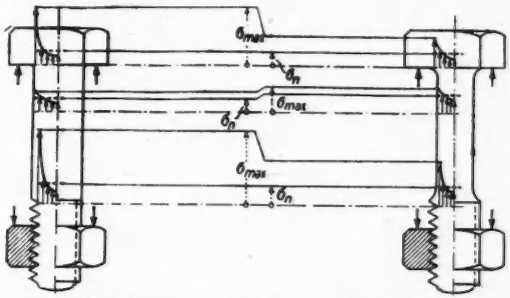


Fig. 21

4. Bolts with Turned Down Shank, Elastic Bolts.

Although theory and practice has given proof, time and again, of the superiority of elastic bolts over standard types, their use is still not so universally adopted as would be justified by merit.

The fact that the bolt shank is reduced to a smaller diameter over a considerable length of the shaft does not mean that its strength is impaired (Fig. 22). The weakest section of a machine element, e.g., bolt, determines its maximum load carrying capacity and this, in case of a bolt, is at the end of the thread. The smaller shank diameter gives greater elasticity to the bolt and by this strengthens the weakest section and thus the whole of the bolt.



Standard Bolt Fig. 22 Elastic Bolt

Bending movement and deformation due to impact stress is taken up mainly by threaded portion.

The whole of the shaft participates in bending. Threaded portion thus partially de-stressed.

41. *Bolt stressed by impact or by oscillating load.*—Figs. 23 and 24 show the Wöhler curve for impact loading in relation to the shank diameter. The advantage of a smaller diameter is apparent.

The use of elastic bolts is limited to instances when

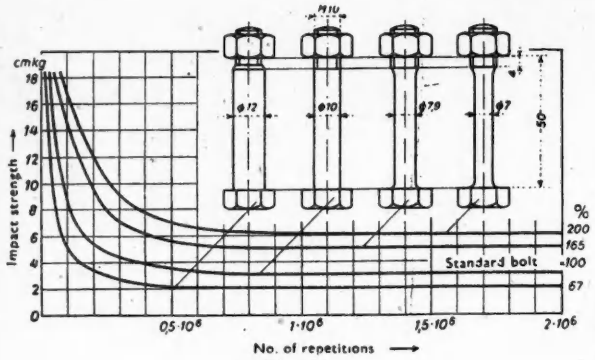


Fig. 23

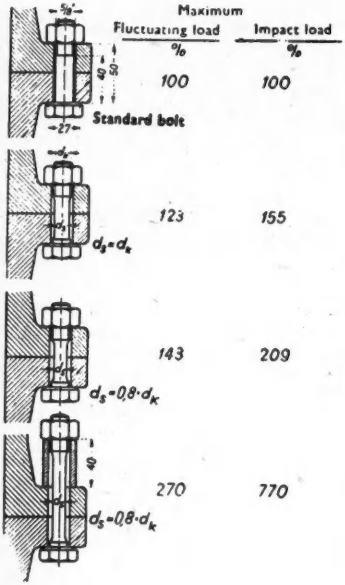
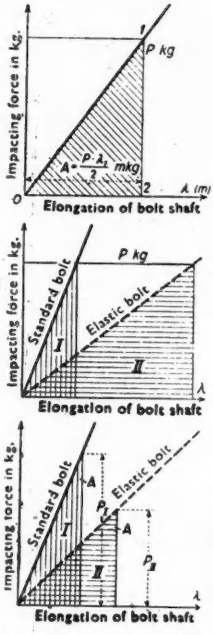


Fig. 24



Figs. 26, 27, and 28

the nature of application justifies this, as is the case when the load is impact or variable, or when the bolt has to resist internal working pressures. In about 95% of the cases, however, standard bolts give satisfactory results.

42. *Bolts in bending.*—More than one reason might be responsible for bending of bolts: expansion due to heating, working load, shape of parts to be bolted, etc. In consequence a stress will be set up in the bolt which will be superimposed on to the normal stresses. Just for such applications the advantages of elastic bolts are predominant (Fig. 25).

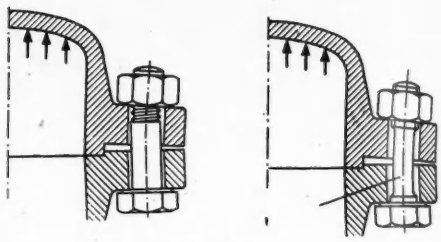


Fig. 25

43. *Impact loading.*—If a sudden impact is acting on a bolt, this must be absorbed in work done in deforming the bolt, strictly within the elastic limit. The force taken up by the bolt is $A = \frac{P\lambda}{2}$ mkg and is represented by the triangle 0-1-2 in Fig. 27. If the value of A is fixed then P will depend solely upon the stiffness of the bolt, being the higher the greater the stiffness. Figs. 27 and 28 show clearly that for the same stress, P, in the bolt the load absorbed is greater, or if A is the same the stress is smaller, in elastic bolts. If the cross section of the bolt shaft is not uniform, the weaker section will be stressed higher, of course, and it is necessary to make the turned down portion of shaft long (Fig. 29). Experiments and theory are in full agreement (Figs 23 and 24).

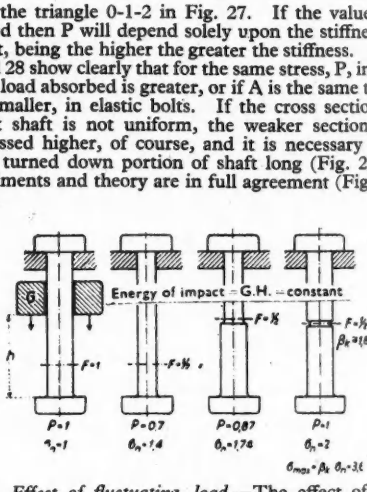


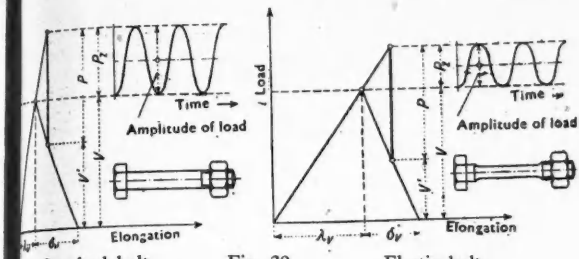
Fig. 29

44. *Effect of fluctuating load.*—The effect of a fluctuating load upon standard and elastic bolts is shown in Fig. 30. Under comparable conditions, the amplitude of load fluctuation is smaller with elastic bolts than with standard types. This is a very important characteristic as the amplitude of load fluctuation is the most important factor on which the endurance strength depends.

45. *Dimensioning elastic bolts.*—The diameter of elastic bolts cannot be reduced arbitrarily: (1) During

TABLE I.

Bolt diameter d mm	inches	Ratio $\frac{f_s}{f_k} = \frac{\text{shaft cross section}}{\text{core cross section}}$ $\frac{mm^2}{mm^2}$ if tenacity of material is: 40 kg/mm²	60 kg/mm²	80 kg/mm²	100 kg/mm²
31	1¼" und darüber	0,80	0,77	0,72	0,70
28	1⅛"	0,85	0,80	0,75	0,70
25	1"	0,90	0,85	0,80	0,72
22	⅞"	0,95	0,90	0,85	0,75
20	¾"	1,00	0,95	0,90	0,80
18	–		1,00	0,95	0,85
16	⅝"	below stepped line $d_s = d$		1,00	0,90
14	–				0,95



Standard bolt Fig. 30 Elastic bolt

tightening of the nut the elastic stress limit must not be exceeded. (2) The endurance strength must not be exceeded by the fluctuating working load. The ratio of endurance strength of the threaded portion σ_w^K to that of the plain part σ_{wz} varies with the material used and has usually values between 0.43 and 0.70. High tensile strength of the material affects adversely this ratio as the tenacity increases only slightly the strength of the threaded portion, while the endurance strength of the flat portion is almost proportional to it. Table I gives reference figures for elastic bolt dimensions.

46. *Influence of high temperature.* For moderate working pressures and temperatures up to 400 °C good quality standard bolts and nuts can be used safely. At higher temperatures however, an additional stress is set up in the bolts, so that the total stressing is made up as follows :

(1) Static stress due to tightening of nut (depends also upon type of packing provided, e.g., soft or hard).

(2) Part of working stress, P_z.

(3) Stress due to bending of bolt shank.

(4) Stress due to differential temperature of bolt and jointed parts, e.g., flanges. This is especially marked during starting, as the temperature of the bolt is lagging behind that of the machine part.

(5) Stress due to general rise of temperature.

461. *Bolt material for high temperatures.* The choice of material will depend principally upon the behaviour of the particular material at high temperature. Steel, for instance, deforms (stretches) rapidly when heated, and creeping continues over a long period. This, however, is strictly speaking only true for plain bars ; notches, like threading, reduce considerably deformation so that endurance tests do not produce creeping and the fracture is without much deformation. Experiments carried out on plain bars should not be regarded, therefore, as the sole test for bolt material in respect of the choice for heat resisting applications. To-day, mainly Cr-Mo steels are used for such applications ; Vanadium is added in some instances to the alloy. Ni-Cr alloys are not recommendable as they become hot-short. Copper steels and Mn-Si steel, too, give poor results.

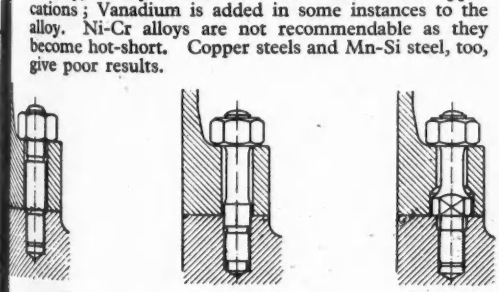


Fig. 31

462. *Design of heat resistant bolts and nuts.* In part the same principles apply to heat resistant bolts and nuts as to standard types: large radius of curvature at thread roots and at head ; reduction of plain shank diameter ; bending stresses to be avoided as far as possible. Dimensioning should be based on endurance strength. To keep creeping low, the shaft diameter should be turned down less than bolts in cold application. Figs. 31 and 32 show some designs adopted for heat resistant applications.

463. *Manufacture of heat resistant bolts and nuts.* Special care must be exercised to give the thread profiles a clean finish. Whitworth threads

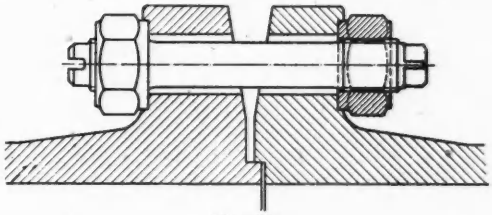


Fig. 32

are usually used, as they offer certain advantages, such as larger core section (about 10%) and smaller friction of thread profiles. During assembling the static stress applied due to tightening must be carefully checked by measuring the elongation of the bolt shaft.

5. Material, Manufacture, and Strength Figures.

51. *Standard steel bolts.* The results of endurance strength investigations, carried out on a large number of standard steel bolts, are shown in Fig. 33. It can be seen that the maximum permissible load fluctuation is almost constant over the whole range of static stressing. This, too, bears out the fact that the static stress is of secondary importance in comparison with the endurance strength. Only when the static stress becomes very small (which does not occur in practice), is the permissible load fluctuation adversely affected.

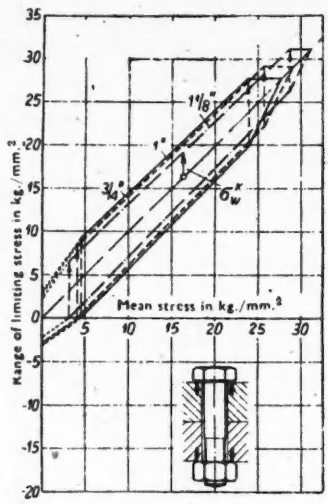
The same illustration also shows the influence of bolt shaft diameter ; the advantage of smaller diameter over larger ones is clearly indicated (see also Fig. 34). Tests on very large diameter bolts are lacking, nor is the effect of fineness of threads established as yet.

The average working stress fluctuation which is permissible with cut, milled or ground threads is about $\sigma_w^K = \pm 3\text{-}4$ kg/mm². Set screws endure a somewhat greater stress and further improvement is possible if cast iron bushings are employed. The corresponding figures for set screws become : $\sigma_w^K = \pm 6\text{-}7$ kg/mm² for steel bushing and 7-8 kg/mm² for cast iron bushing.

52. *High quality and alloyed steel bolts.* Very little improvement of strength can be achieved by using special steel as working material. As mentioned before, this is due to the adverse effect of the notched, e.g., threaded, portion of the bolt shaft which almost nullifies the improvement obtained on the plain portion.

53. *Material for cut screws.* In view of the aforesaid, the choice of material will depend upon its notch impact strength and yield stress ; high yield stress permits the application of a high static stress. The use of high quality and alloyed steels will, therefore, be limited to :

(1) Small screws (less than ¾ in.), if for constructional reasons they must sustain a large stretch.



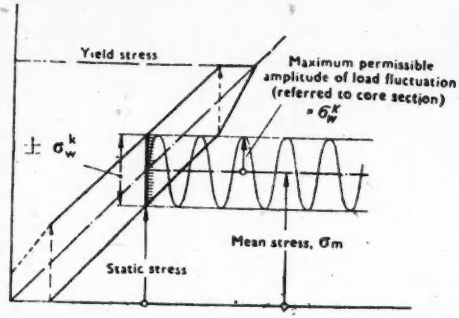

Yield stress
Maximum permissible amplitude of load fluctuation (referred to core section) = σ_w^k
$\pm \sigma_w^k$
Mean stress, σ_m
Static stress

Fig. 33

(2) Larger screws, if they are exceptionally highly stressed during tightening.

(3) Heat resistant applications.

In the above three cases consideration must be given to the following:

(a) To use special steel with great ductility, not having too high yield stress in respect to the breaking stress. The notch impact strength of such steels is high.

(b) To avoid high alloy steels which have a small notch impact strength. If the diameter of the bolt shaft is more than 1" hardening becomes very irregular.

(c) Heat treatment after cutting the thread reduces the endurance strength.

Nitride hardening constitutes an exception in this respect, as it improves the tensile endurance strength. However, it requires very careful technical and constructional supervision when applied to the screw thread.

As a general rule, the best material for cut, milled and ground screws is unalloyed mild steel. It has strength, satisfactory for all standard bolt fastening purposes.

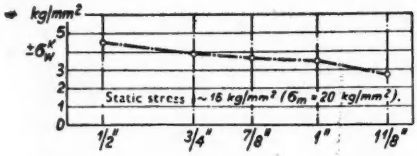


Fig. 34

54. *Special manufacturing method.* There are a number of screw types on the market which, as a result of special design and processing methods, are claimed to have strength twice that of standard types. Especially in light alloy construction, their use has proved to be almost indispensable. Their high strength is due, apart from a careful choice of material, to cold rolling of the threaded part. Smaller screws can be processed by cold rolling alone, and their endurance strength is, in this case, not much higher than that of cut screws. But with larger types, cold rolling is applied only to the cut, milled or ground thread, whence their strength is very much increased. Rolling is particularly beneficial at the thread roots, and therefore, when rolling is applied to the whole of the threaded profile, the danger arises that the root—which carries the bulk of the load—will not be rolled uniformly.

The improved strength of rolled screws and the like is brought about by the smoother and closer surface of the metal, as well as by the internal stress set up in consequence of the plastic deformation (Fig. 35). Heat treatment, after cold rolling, is liable to destroy the internal stress and is, therefore, to be avoided.

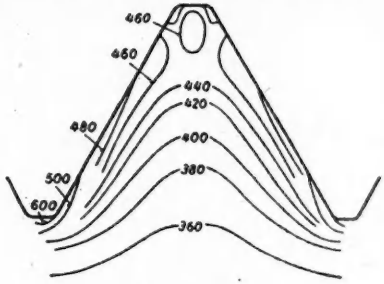


Fig. 35. Hardness of cold rolled thread.

55. *Screws in light metal bushing.* Special attention must be given to screws in light metal bushing. As a general guidance, the threaded portion in engagement should be about 1.5 to 2 diameter long; with cast light alloys not less than 2d. Figs. 36 and 37 show some typical solutions for such applications.

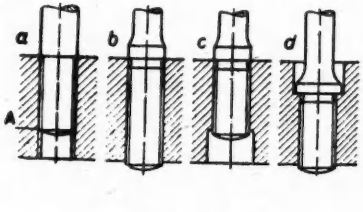


Fig. 36

a Standard solution A = Fatigue failure
b Improved design with no danger of fatigue failure.
c Very satisfactory solution, but expensive and not always feasible.
d Best solution.

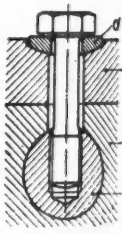


Fig. 37

a and *b* light alloy.
c cast steel cylinder

6. Static Stress due to Tightening Nut.

In general loose bolts or studs will resist only a fraction of the working load applicable to well tightened bolts (Fig. 38).

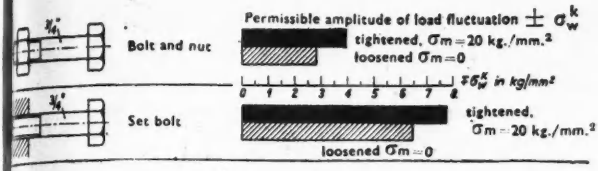

Permissible amplitude of load fluctuation $\pm \sigma_w^k$
Bolt and nut
tightened, $\sigma m = 20$ kg./mm.²
loosened $\sigma m = 0$
$\pm \sigma_w^k$ in kg/mm²
Set bolt
tightened, $\sigma m = 20$ kg./mm.²
loosened $\sigma m = 0$

Fig. 38

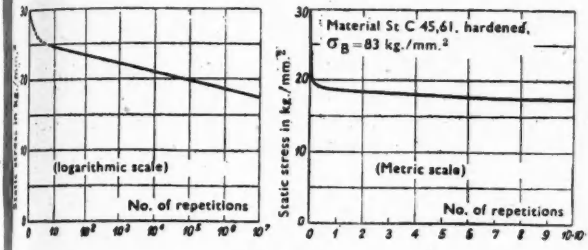


Fig. 39

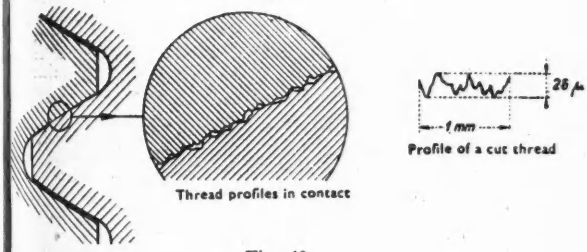


Fig. 40

61. *Loosening during application.* The fact that well tightened bolts and nuts, etc., are becoming loose during application when the working load is impact or fluctuating, has been known for a long time. It is possible to measure the amount of decrease of static stress and Fig. 39 shows graphically the usual amount of reduction. It can be seen that already after the first ten repetitions a considerable reduction has taken place, and after 100,000 repetitions the static stress has fallen to about 65% of the original value. Following this, there is a gradual decrease of static stress at a very slow rate.

62. *The causes of reduction.* The main reason for this is the plastic deformation of the surface irregularities of all stressed surfaces. Cut threads of standard quality show surface irregularities of an average height of 20-40μ (Fig. 40). Tightening, and the first few load impacts rule off the peaks of these irregularities. This is carried further as the load continues to rub the surfaces against one another and the screw "sets." This plastic deformation is, however, not confined to the thread profiles, but takes place along all surfaces, such as the bearing surface of the nut, and continuous throughout the whole period the load is acting, though at a much reduced rate after some time.

63. *The influence of number of joints to be bolted together.* From the preceding section it follows that the number of

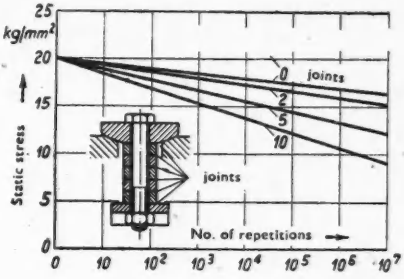


Fig. 41

joints (Fig. 41) is an important factor regarding loosening, as each joint contributes another stressed surface which will suffer plastic deformation. Experiments fully support this. The reduction of static stress is directly proportional to the number of joints.

Two conclusions can be drawn from this: (1) Important bolted joints must have a carefully smoothed finish, and (2) it is advisable to keep the number of joints as small as possible.

In multi-joint applications, too, the elastic bolt gives better results. If namely the setting of the bolt is $\Delta\delta$ then the static stress is less affected in case of elastic bolts than with standard types, as can be seen from Fig. 42, and from the experimental results given in Fig. 43.

64. *Influence of processing method.* Rolled threads have an inherently smoother surface than others and the average height of surface irregularities is between 3 and 6 μ as opposed to 20 and 40 μ for cut threads (Fig. 44). Therefore, rolled threads will loosen to a much lesser extent in application and this is also verified by experimental results (Fig. 45). The advantages of rolled threads over cut, milled or ground ones can be summarised as follows:

(1) Higher endurance strength, (2) better results in bending, (3) Higher yield stress, hence it can be higher stressed when tightening, (4) Keeps better the static stress.

65. *The magnitude of static stressing.* Inadequately tightened bolts and nuts will loosen more readily during the subsequent application of load, than when the initial

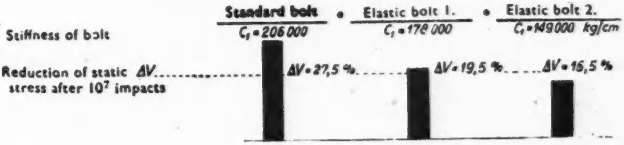

Standard bolt
$C_1 = 206\,000$
Elastic bolt 1.
$C_1 = 176\,000$
Elastic bolt 2.
$C_1 = 149\,000$ kg/cm
Stiffness of bolt
Reduction of static stress after 10^7 impacts ΔV
$\Delta V = 27,5$ %
$\Delta V = 19,5$ %
$\Delta V = 16,5$ %

Fig. 42

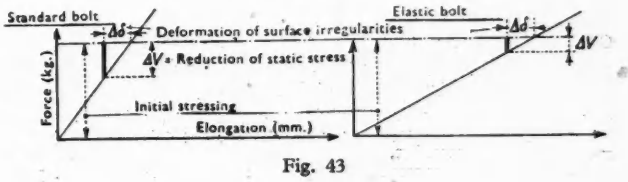


Fig. 43

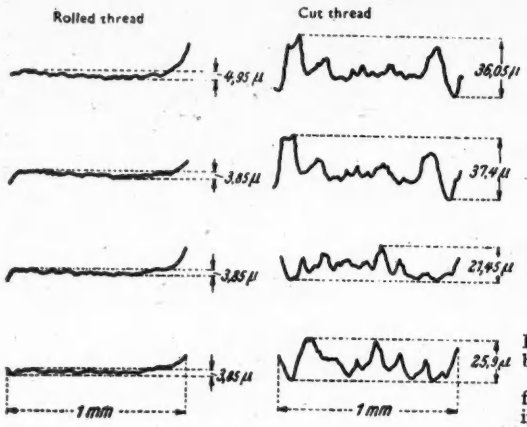


Fig. 44

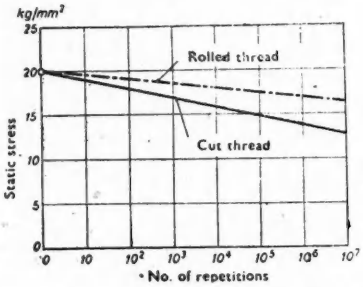


Fig. 45

static stress is higher. This is shown in Fig. 46. Thus when the initial stressing is only 10 kg/mm², the stress falls by about 50% after 10^5 repetitions and becomes liable to fatigue failure. If, on the other hand, the tightening pressure is 20 kg/mm², 10^6 repetitions are required to produce the same drop of static stress.

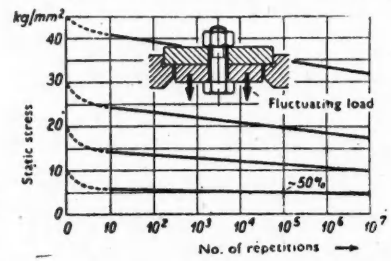


Fig. 46

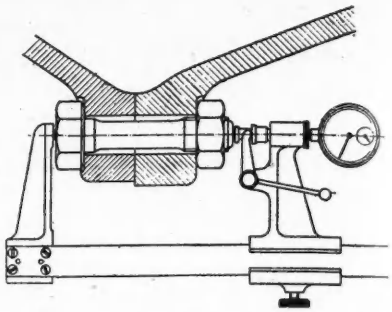


Fig. 47

Henceforward it decreases only slightly, but never below a value that would make it liable to fatigue failure.

The correct tightening pressure cannot be estimated from theoretical considerations; practical experience indicates that about 60% of the yield stress would be a suitable value.

Because adequate tightening of nuts is an important factor, hydraulically and electrically operated machines were devised which make tightening independent of the skill of the workman. This way a uniform pressure can be applied which also reduces the torque and hence permits stronger tightening of the nut. The value of the stress in the bolt shaft is indicated by the elongation of the shaft on a special instrument (Fig. 47).

7. Multi-Bolt Joints.

71. *Influence of number of bolts used.* Recent investigations have verified that the endurance strength of a bolted joint is higher with increasing number of bolts (Fig. 48). The reason for this is:

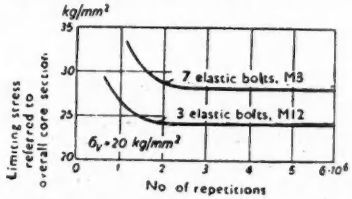


Fig. 48

(1) Smaller bolt shaft diameter is needed and hence the reduced stiffness of bolts results in a smaller value of the force, P_Z (Section 21).

(2) The permissible amplitude of working load fluctuation is greater with smaller shaft diameter (section 44).

(3) Load distribution becomes more uniform.

(4) Bending sets up smaller stresses in the bolts.

Insufficient consideration is given, very often, to the rule that in multi-bolt joints the length of bolts should be constant. The strict adherence to this rule is imperative if the load is impact or fluctuating.

CARBON OFFERS SOLUTION TO MATERIALS PROBLEMS

By Fred. W. Korfmann. (From *Machine Design*, Vol. 14, No. 5, May, 1942, pp. 61-65).

Carbon is a familiar material in electrical applications. Perhaps for this reason it is sometimes overlooked as a structural engineering material. Already, however, it has had extensive mechanical application and, therefore, deserves consideration not only as an alternative material, but as a permanent addition to the designer's materials specification list.

Carbon and its generic form graphite are obtainable in a wide range of physical properties. As in the case of any engineering material, certain design considerations peculiar to itself must be observed in the handling and specification of carbon parts. In order to illustrate its possibilities a series of applications and case histories will be cited followed by specific design and physical property data.

Application study has been divided for the sake of

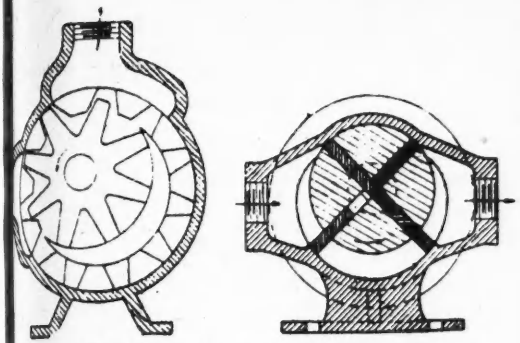


Fig. 1. Moulded carbon rotors give outstanding life in corrosive service as well as under conditions of poor lubrication.

convenience into three classes: (1) structural, (2) frictional, and (3) electrical. It is hoped that these discussions, covering typical carbon uses, may serve to indicate solutions to many present-day engineering problems.

Pump gears and blades, formerly made of bronze and various laminated plastics, have been replaced successfully by carbon. Because of its chemical inertness, it was first given consideration for applications in chemical processing equipment. As a result of its lower friction losses and lower rate of wear when operating against metal parts, it rapidly became apparent that an extension of its use to non-corrosive conditions was amply justified. Such additional qualities as freedom from swelling or warping contribute to this conclusion. In addition, in blade type rotary pumps, carbon's low specific gravity and its ability to operate for long periods without lubrication are important factors. Operation of such pumps at much higher speeds are permissible for these two reasons. Two such applications are shown in the drawing, Fig. 1.

The pump shown at the left of Fig. 1 operates at 1200 revolutions per minute, handling, at low pressure, a water solution of 9% sulphuric acid, 16% sodium sulphate, and 1% zinc sulphate at a temperature of 40°C.

The vane type pump, shown at the right of Fig. 1, also operating at 1200 revs. per minute, handles oil and other liquids at pressures up to 1000 pounds per sq. in. As an example of higher attainable speeds, 2-inch diameter carbon rotors have been used in air pumps operating at 3300 revs. per minute. In pump applications such as these two, the maintaining of minimum clearance between the rotors or vanes and the housing is of vital importance. Because of its lower coefficient of thermal expansion (0.000001 per degree F), the use of carbon for these parts leads to unusually high operating efficiencies.

In gasoline metering pumps serious trouble was experienced as a result of gumming and sticking of the valves as well as the scouring of the zinc base die-cast housing upon which the cast-iron metering valve operated. In an effort to overcome these difficulties, die-cast aluminium was tried with some success. A specially compounded and designed carbon valve was substituted with improved results. In Fig. 2 are shown the two original metal valves on the left, and the finally developed carbon valve on the right. This valve is an excellent example of the possibilities for moulding special shapes, and will be discussed in greater detail in the section devoted to design date.

Another interesting application is slide valve for gas meters. Formerly a white metal slide valve was used, operating against a similar white metal seat. High and irregular friction and sticking of the valve due to gummy formation on the valve seat as well as noisy operation were experienced. After a series of tests, a grade of density of carbon was developed which would both seal the gas across the valve and keep the grate clean. Quiet operation, low even friction, and a low rate of wear are obtained. This application also exemplifies the manner in which metal inserts may be applied to carbon parts.

Another interesting valve, Fig. 4, seals ten pounds pressure across distributing parts in a rotary air governor application. The carbons, as shown, rub against the inside diameter of a magnesium cylinder at approximately two revolutions per minute; the entire life of the assembly has been estimated at 45,000 revolutions.

Clutch plates and rings, formerly made of cork and metal, have been successfully replaced with carbon parts. The coefficient of friction in one application has remained constant at 0.22 to 0.35 over a period of years. The friction surface is either on the inside diameter, or face. Freedom from squeaking is obtained.

Illustrated in Fig. 3 are two redesigned variations of an electrically operated plunger type steam valve in which trouble had been experienced, when a cast-iron plunger was used, by seizing of the plunger on its three supporting guides. The upper drawing illustrates how carbon was used for the plunger without any other redesign of the valve. In the lower drawing of Fig. 3 is shown a redesign that permits the use of a simple hollow carbon cylinder resulting in appreciable economy.

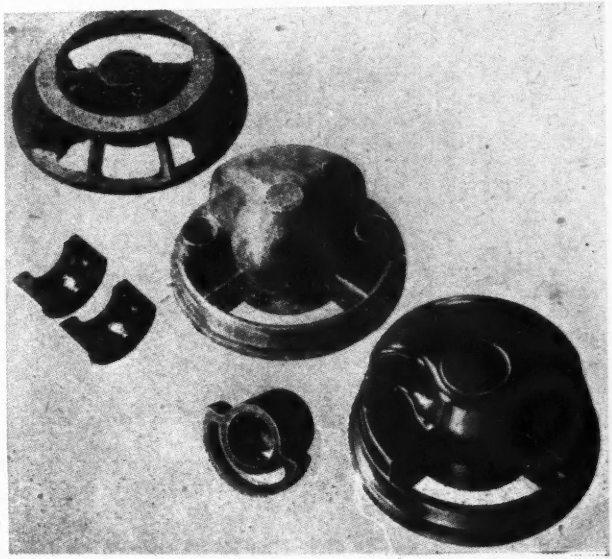


Fig. 2. Evolution of gasoline pump metering valve from cast iron to aluminium to carbon results in the elimination of sticking.

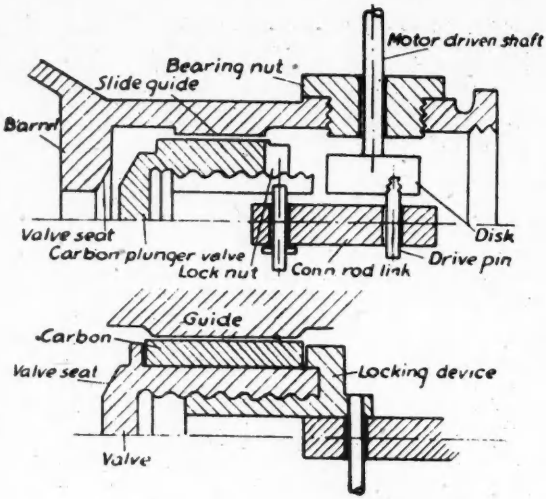


Fig. 3. Direct substitution and a redesign for optimum use of carbon result in the solution of operating difficulties with cylindrical valve.

In this steam valve, which is also used for water and fuel oil, the steam pressure at the thinnest section of the carbon is 160 pounds per sq. in. In this and also manually operated valves, special high density and high impact resistance grades of carbon are employed. Many such manually controlled valves are operated by driving forks or similar mechanisms which fit into moulded grooves or blind holes in the carbon. To reduce local wear, metal fittings for hole reinforcement and similar strengthening purposes are moulded into, or shrunk on, the part.

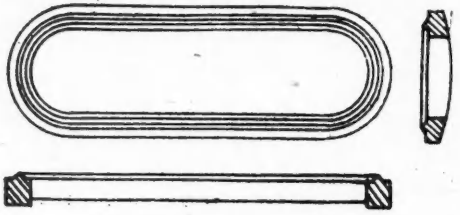


Fig. 4. Distributing parts of a rotary air governor are sealed again ten pounds per sq. inch pressure.

Fig. 5. Corrosion resistance and low expansion rate are important reasons for using carbon in pump applications.

Structural strength and piece size in the required density are the limiting design factors, and it will be seen from the illustration, Fig. 5, how these factors are handled. In such designs, consideration is given to metal plating or spraying of the finished assembly to increase shock resistance. Ceramic glazes can also be applied to such assemblies for improved appearance, reinforcement, and protection. Rubber can be readily vulcanised to carbon, which material acts as a casing, shock absorber, or cushion for applications in severe service.

Low Inertia Important in Wabble Plates.

In meters of the wabble plate type, Fig. 6, for liquids and semi-solids, chemical stability, low coefficient of expansion and low rate of wear are important considerations, as is also the desirability of maintaining at a minimum the inertia of all moving parts. In such applications the use of carbon for the wabble plate achieves these ends in addition to permitting manufacture to extremely close tolerances. Moulding and other manufacturing processes to attain efficiency and minimum cost are problems for the carbon manufacturer.

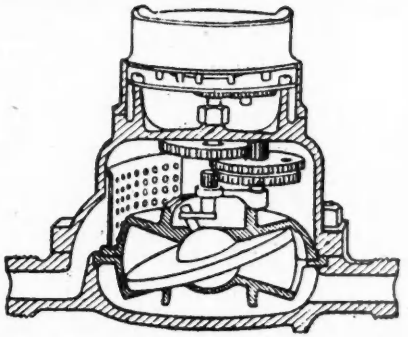


Fig. 6. Possible close manufacturing to levances contribute to the use of carbon for wabble plates.

Carbon bearings and bushings are used principally where high temperatures demand self-lubricating properties, or where gases or liquids would prevent satisfactory fluid lubrication. One such part is the axial cylinder pump illustrated in Fig. 7. In this case hemispherical carbon parts fastened to the end of the piston rod bear on metal inserts in the piston, actuating the wabble plates.

Another interesting bearing job is on a 1000 gallon sump pump. Here a carbon steady bearing is employed eight feet from the motor drive. It replaced a bronze bearing which was pounded out of shape in about six months. The carbon bearing differed from the metal in that it would not flow and become elliptical as had the metal. The carbon had been run over several years and at the last inspection had worn less than 0.001 inches; no measurable shaft wear. Some applications in paper mills require the carbon bearing to support over 1000 pounds per sq. in. at low speed. An outstanding application of a metallic carbon composition seal is that in automotive, industrial, and other fluid drives. Here, the seal floats between two metal sur-

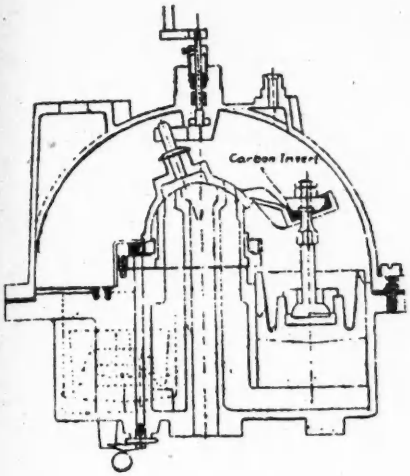


Fig. 7

faces at high speeds and temperatures in a manner described in detail in many recent publications.

Important developments are a new cartridge type oil seal which solves the problem of obtaining a carbon seal requiring small space. In seal service, speeds as high as 60,000 revs. per minute at 30 lbs/sq. in. pressure have been satisfactorily handled. There are many successful oil seal applications on aircraft.

Fastening Problems Solved.

Problems of attaching or fastening carbon parts to adjacent parts in an assembly have in the past caused considerable difficulty. As a result of the development of new methods carbon may now be satisfactorily attached to metallic bellows, or other metal parts; may be vulcanised to rubber; may be metal sprayed or plated, and may be coated with porcelain enamel or other ceramic materials.

Use of carbon and metallic carbon compositions in piston rings or pumps and compressors is so well-known as to require little mention here. An outstanding advantage of this application is that in addition to its self-lubricating qualities, the carbon imparts a corrosion resistant film on the cylinder wall in the same manner as on the surface of shafts running in carbon bearings.

In several instances it has been found preferable to use cylinder liners of carbon in conjunction of cast-iron or other metal piston rings. One application on a weighing scale indicates when such a scheme is desirable. As originally designed the scale utilized a carbon plunger operating in a metal cylinder. Satisfactory performance was obtained in the normal range in which the scale was used. However, outside this range, sticking of the plunger often occurred. This was found to be due to the fact that the carbon plunger polished the section of metal liner corresponding to the normal working range. Outside of this range the liner developed oxide films which altered the wall diameter and changed the friction drag. The solution to this difficulty was in making the cylinder lining of carbon and the plunger of metal. Thus regardless of the working range of the scale the metal plunger attained a continually polished surface.

For extremely large sized applications, problems of required density and necessary mechanical reinforcements are still major obstacles; however, on applications of moderate size, successful use of frictional equipment has been obtained even under high speed operating conditions.

Produces Glaze on Bearing Metal.

The property of being able to produce a glaze or highly polished surface on the co-operating metal parts with consequent low wear rate has resulted in the development of special carbon grades for the trolley shoe inserts of street railway systems. Incidental to the advantages of greatly reduced wear and increased life of the overhead wires is the fact that static radio interference is also, thereby, eliminated. Outstanding requirements for the application are fairly hard compositions, low water absorption, self-lubrication, and good electrical conductivity. All of these specifications are met satisfactorily by the assembly shown in Fig. 8. A metal shroud or housing is designed to accommodate the carbon shoe which alone bears on the wire. The metal housing adds to the mechanical strength of the assembly and permits simple replacement of the carbon shoe. When bronze or hard steel shoes were used, the average life of overhead wire on street railway systems was only from about 20 to 30 years. Experience with the carbon insert indicates that this life will be increased to over 100 years. Current-carrying capacity of similar assemblies in mine service is up to 200 amperes. Contact pressure between the collector and the wire is maintained at a minimum of 10 pounds.

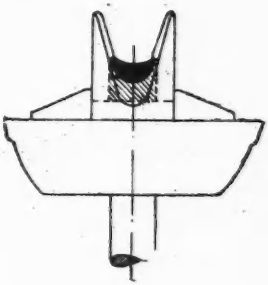


Fig. 8

Carbon shoe inserts greatly increase life of overhead wires in street railway systems.

An analogous development is the application of carbon strips to electric pantographs. Life of these strips is in the neighbourhood of 50,000 miles. The problem in this case was the development of a sufficiently strong carbon compound, but one which still possessed the desirable frictional and electrical properties. This has been accomplished ultimately by making the strip a composite of three or four strips extending the full length of the pantograph pan. Problems of fastening and methods of reducing shock to a minimum without sacrificing full support for their strength have been solved.

Physical properties of carbon are tabulated in Table I, and contrasted for the sake of comparison with aluminium die castings and phenolic plastic. The wide range of compressive and tensile strengths provides a key to the large number of available compositions and compounds which may be specified by the designer. A brief discussion of the process of making carbon parts will provide a broad picture of the reasons why size, shape, and contour affect homogeneity and physical properties of the final part.

TABLE I.

Property	Moulded Carbon	Aluminium Die Casting	Phenolic Plastic
Compressive strength, lbs./sq. in. ..	2,000-25,000	9,000-46,000	16,000-36,000
Tensile strength, lbs./sq. in.	400-3,500	16,000-32,000	4,000-11,000
Shear strength, lbs./sq. in.	3,200 max.	18,000-32,000	10,000-15,000
Impact strength, ft. lb. Izod	0.10-1.2	†	0.10-2.7
Specific gravity	1.4-2.2	2.6	1.27-2.09
Temperature limits, °F.	850*	—	240-300
Chemical resistance	Unaffected	Limited	Limited
Thermal expansion per °F.	0.000001-0.000006	0.000010-0.000015	0.00002-0.000075
Hardness	40-135 (scler).	75-110 (Brinell)	30-45 (Brinell)
Elastic modulus, lbs./sq. in.	1.33×10^6-2.42×10^6	10×10^6	0.5×10^6-4×10^6

*(Graphite grades suitable for higher temperatures).
†(Grades are obtainable with lower and higher values than plastics).

Basic Ingredients and Process.

Basic materials are natural graphite, artificial graphite, petroleum coke, lampblack and retort carbon; with pitches, tars and other binders. The proportion of each is controlled for specified results, and metals in powdered form may be added for special qualities. The powders are thoroughly mixed with binders and then pressed to the required form. Following this, the moulded (green) blanks are kilned at high temperatures, such that the binder is carbonised. This operation requires as many as ten days, depending upon the grade. After cooling and inspection, any necessary machine operations are performed to provide finished dimensions.

Thus in heavy or irregular sections, variations in pressing pressure throughout the cross section of the piece as well as inevitable temperature gradients existing in certain stages of the baking operation may contribute to a uniformity problem across the section of a part. This condition can be, to a large extent, controlled by the carbon manufacturer based upon his long experience in the art. For these reasons, the compounds in a given part should be dictated largely by the manufacturer.

As far as design criteria are concerned, any object which can be die cast or plastic moulded can be moulded of carbon. An example of design development is provided by the gasoline meter valve, previously discussed and illustrated in Fig. 2. The change from the original cast-iron valve to the aluminium die cast type necessitated certain design changes, principally increased size and shape of the drive shaft spindles which enter at the base of the valve. The driven fork which fits into blind holes in the top of the valve and actuates the computing gears was also slightly altered. The original cast-iron valve employed a slot, and this shaping together with the fork used was undesirable in both the aluminium die casting and the carbon valve. As noted from the illustrations, the carbon design maintained essentially the same shape as the die casting. The final carbon valve weighed one half as much as the cast-iron and slightly less than aluminium.

Moulded to Close Tolerances.

Some carbon compounds can be moulded to within 0.001 inch total tolerance; closer dimensional limitations necessitate special finishing operations such as grinding, polishing, and superfinishing. The latter operation, when applied to the noses of shaft seals and rotating joints, affords perfect sealing even while the joints are stationary.

Metal fittings for reinforcing or operation may be either moulded in or applied after the finished piece is taken from the die. These points should be considered by the designer. Self-tapping screws and similar fastenings are used satisfactorily for attachment to co-operating machine elements. In developing the finished design for a carbon part it is desirable from the stand point of economy that finished-machining operations be held to a minimum. While most grades are readily machinable with tungsten, carbide tips, or diamond tools, the majority of machine work is done by grinding.

STEEL PRODUCTION IN GRAPHITE-BAR HEATED FURNACES

By WERNER GELLER and HANS KONIG. (From *Stahl und Eisen*, Vol. 62, No. 1, January, 1942, pp. 9-14).

FROM the many types of electric heating methods available, electric arc and induction heating have been utilized for steel production as far back as the beginning of this century. It is, therefore, very remarkable that resistance heated radiating bodies were not employed until quite recent times, although practice has given indication as to the practicability of this method. Recent experimenting and development of furnaces on this line has produced furnaces from 100 kg to 1 ton capacity, graphite bars providing the heating elements. The radiators are fed by low voltage, high current density A.C., and the heat is imparted to the surrounding charge almost solely by radiation.

In the following a brief description of such furnaces will be given together with some operational details.

Description of Furnace Plant.

Graphite bar furnaces are constructed as drum furnaces with 1 or 2 radiators, or as open hearth furnaces with 3 radiators. Some data of 1 and 3 radiator types are given in Table I.

One end of the graphite bars fits into the conical seating of a water cooled contact maker, by means of which they can be quickly withdrawn from the furnace and a new one inserted if necessary (Figs. 1 and 3). The other end of the bars is rounded off and fits into a spherical recess in a graphite intermediate piece. Another contact maker is pressed against the graphite piece by a spring, so that the elastic connection permits free heat expansion of the bars and provides, at the same time, a good electric contact between the bar and the

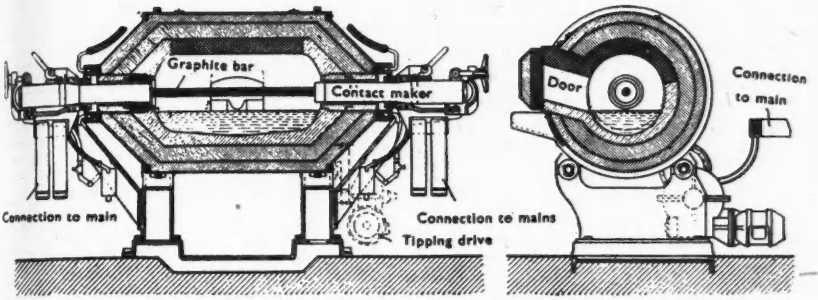


Fig. 1

TABLE I.

Type of Furnace	Capacity kg.	Power kVA	Graphite Bars		
			Number	Length, mm.	Diameter mm.
Drum furnace	30	60	1	365	30
	100	120	1	765	30
	200	180	1	970	35
	300	200	1	1200	50
Open hearth furnace	1000	450	3	1200	50

electric mains. It is important that the fit between the contacts and the spaces through which they enter the furnace should be as air tight as possible in order to prevent the entry of atmospheric oxygen and so reduce burning away of the charge and the graphite bars.

The temperature of the graphite bar is very uniform all along its effective length, even when after long use it is irregularly burnt down.

Figs. 1 and 2 show details of a 300 kg, single bar furnace. The graphite bar is arranged in the axis of the furnace and can be attached, together with the

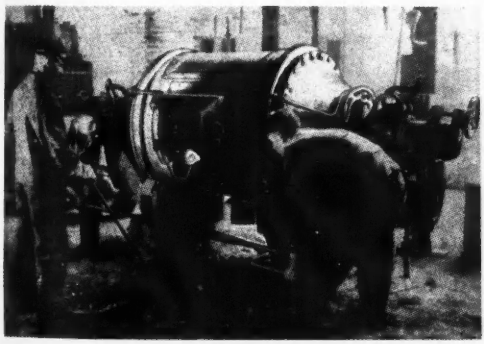


Fig. 2

contact maker and cooling device, either to the furnace or on to fixed supports, in the latter case the electric connection and changing of the bars is easier. This is especially advantageous when the furnace is run alternatively with acidic or basic lining. The door frame and bushing of the contact makers are water cooled. The door is pressed tightly against the frame by means of a hand wheel, and is fitted with a tap hole at its lower end through which the liquid steel can be tapped off in small quantities without permitting oxygen to enter the furnace (Fig. 2).

The furnace, itself, is supported on roller bearings. Of especial importance is the fact that the drum furnace can be given a rocking motion of some 120° so that the hot furnace arch above the level of the charge can be brought into contact with the charge. If this rocking motion is periodically repeated, it will save heat, contribute to longer life of the lining, and provide efficient mixing of the charge.

In double bar furnaces, the graphite bars are arranged parallel in a horizontal plane, and the contact makers are attached to the furnace. Otherwise the construction is the same as that of a single bar type.

A larger furnace, 1 ton capacity, fitted with 3 graphite bars is shown in Figs. 3 and 4. The furnace roof is secured to the hearth by means of a steel frame. The steel is tapped off through the front charging door which, for this purpose, is fitted with a launder.

Graphite bar furnaces require very little space for accommodation and operation. A 100 kg capacity furnace for instance takes up only 1.5×2.4 m² to which 1.0 and 1.8 m. free space must be added to the right and left of the furnace respectively to allow changing of the bars For the 1 t. type 2.7×3.4 m² is needed with 1.3 and 2.4 m. free space on the two sides respectively.

The furnace is built up of a good insulating outer brickwork, and a firebrick interior. The lining consists of tamping material, firmly rammed on to the fire brick. A barrel shaped wooden core is put into the furnace and burnt out during drying of the lining.

The tamping material is corundum cement, made of fused corundum, some binding material and a small quantity of water. Corundum bricks were first used to line the ducts of the contact makers, but as these could not stand up to the frequent heat variations, tamping material was used instead in later designs. The corundum cement is acidic and, therefore, not all types of steels can be manufactured with this sort of lining. Manganese steel, for instance, cannot be manufactured in it, as manganese would attack the lining and rapidly destroy it. For such steels, tamping with magnesite gives satisfactory results. Ganister for lining, gave very poor results as it melted near the heating bars at the contact makers.

Corundum cement lining is used also for larger furnace units (1 ton). The furnace walls are built of sillimanite bricks or rammed with sillimanite tamping material. The roof has an outer insulating brickwork and a sillimanite brickwork at the inside.

The specific resistance of the graphite bars varies between 8 to 12 ohms $\times$ /mm²/m. According to their dimensions and the output, the voltage varies between 20 and 75 volts. This low voltage is a safeguard against accidents. The current density is, of course, very high, being of the order of 6000 A (33 A/cm²), and the output is about 100 W/cm² of useful heating surface. The mean temperature of the bars is 2500 °C.

A ten-step transformer supplies the heating current. Thus the voltage can be regulated according to the

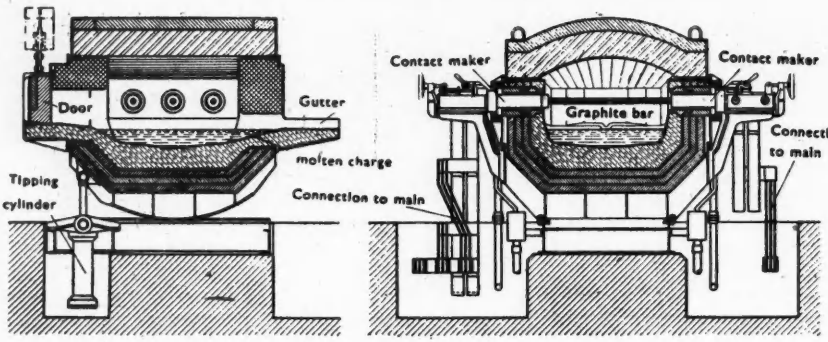


Fig. 3

condition of the bars. The load not being fluctuating, as is the case in electric arc furnaces, the transformer need not be overdimensioned and no condensors are required.

In most applications three-phase A.C. is available. The 3 bars can then be fed with individual control. At high loads on one or two of the phases only, however, disturbances may be caused owing to the non-uniform loading. The Scotch connection is very useful for the two-bar furnace type, or a single phase connection with condensor and choking coil for the single-bar type. Although the efficiency is thus reduced somewhat, this is made good by saving the costs of an adjustable transformer and the electric losses in it.

Fig. 4

Employment as Remelting Furnaces.

As a result of several years' experience with graphite bar furnaces at the Dusseldorf Heerdt Co., operational data became available. The furnaces were used for the manufacture of tool, high speed, and magnet steels as well as of heat and corrosion resistant high alloy steels.

The operation of two furnaces were observed: a 100-120 kg single-bar drum furnace and a 1000-1200 kg three-bar open hearth furnace. As both these were at the time of observation acidic lined, de-phosphorising and de-sulphurising had to be dispensed with, and a high purity charge used.

Table II shows the dependance of the time for melting and refining on the serial number of the operation performed in continuous working. Naturally, the time of the first operation is the longest, and decreases rapidly with the first 4-5 operations then reaches a steady value (Fig. 5). The time of one operation is very satisfactory, once steady conditions are attained.

An important factor, next to the quality of the steel, is the percentage loss in metal during melting, especially when high alloy steel is produced. Analyses of charge and finished product have resulted in the following figures.

For 0.3-1.2% Mn. steel the loss is 40%, but it must be remembered that this is due to the acidic lining. In another 400 kg graphite bar furnace with basic lining, a 12% Mn steel was manufactured with practically no loss.

TABLE II.

100-120 kg. furnace.

Steel		A		B	
Serial number of operation		1 to 3	4 etc.	1 to 3	4 etc.
Duration	Melting ..	100-50	40-35	100-60	60-40
	Refining ..	10-20		25-40	
	Total ..	120-60	60-45	140-85	100-65

1000-1200 kg. Furnace.

Steel		A		B	
Serial number of operation		1 to 4	5 etc.	1 to 4	5 etc.
Duration	Melting ..	180-75	75	180-100	1000
	Refining ..	25-40		45-70	
	Total ..	220-100	115-100	250-145	170-145

A.—High alloy steels with 0.7 to 2.0% C, 4 to 20% Cr, 4 to 12% W, and 5 to 35% Co.

B.—Medium alloy steels with 0.2 to 0.6 C.

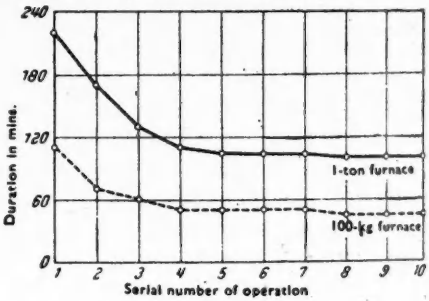


Fig. 5

For 20% Cobalt steel the loss was found to be 0.6-0.8%.

For 1% Mo steel, only 5%.

For 1-4. 5% Vanadium steels the corresponding loss was 1-6%, which is a very good result considering how easily Vanadium is oxidised.

For 2-12% Tungsten steels the loss was 4-2%, decreasing with increasing Tungsten content.

1-30% chrome steels can be manufactured with 2-8% loss. The relatively higher loss, here too, is probably due to the acidic lining.

A comparison with the corresponding figures for basic lined electric arc and acidic lined induction furnaces shows that the graphite-bar furnace operates as economically as the induction type, although considerations must be given also to the differential method of lining and to the fact that the figures for the graphite bar furnace are not yet confirmed by long practice. Nevertheless, the short melting time and the presence of a strong de-oxidising substance, i.e., carbon monoxide formed by oxidation of the graphite bars, is manifested in the small wastage figures. Increased carbonisation, even of low carbon steels, was not observed, the decarbonising property of the slag still predominates.

The quality of the finished products is as high as those produced in any other type of furnace, and regarding the metallurgical properties of corundum cement lining, further investigations are being carried out in the laboratories of the Technical College at Aachen.

Energy Consumption.

The energy consumption will depend, of course, on the serial number of consecutive operations, since the furnace has a considerable heat capacity which must be saturated before steady conditions can be reached. Energy consumption depends further upon the quality of steel produced and the duration of refining. Consumption figures for two types of steels are tabulated in Table III. Fig. 6 shows the overall power consumption during the manufacture of high alloy steels in dependance of the serial number of the operation. As the power consumption was measured before the transformer, it includes also the transformer and conductor losses.

The much greater energy consumption during the first two operations is evident from Fig. 6. It is, therefore, most important that such furnaces be operated continuously during the working hours, and careful arrangements should be made to prevent excessive cooling off during the standby period. It is also recommendable to pre-heat the furnace with a cheaper sort of fuel than electricity when started from cold.

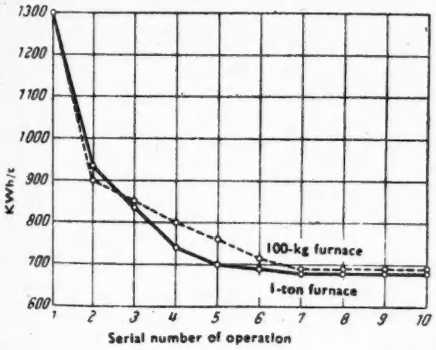


Fig. 6

TABLE III.

Furnace Capacity ..	100 to 120		1000 to 1200	
Power kW { Melting	125 to 90		450 to 400	
Power kW { Refining	90 to 65		360 to 250	
Steel	A	B	A	B
Overall power consumption in kWh/t	680 to 720	850 to 950	680 to 720	800 to 900

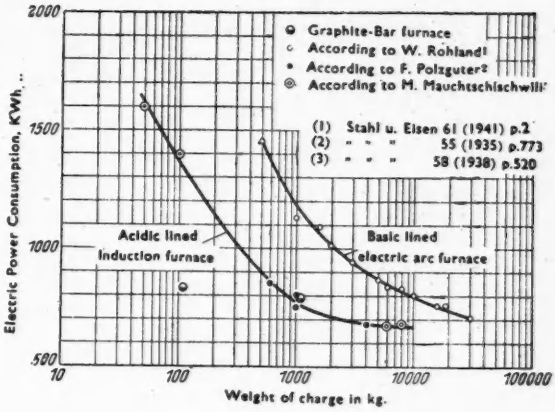


Fig. 7

Table III and Fig. 6 also show the striking agreement of results between the 100 kg and the 1 ton type. As mentioned previously, the efficiency of the drum is greatly increased by the rocking motion and good heat insulation.

Fig. 7 give overall consumption figures for all steels produced in comparison to basic lined arc furnaces and acidic lined induction furnaces. The smaller energy consumption of induction heating is apparent from this figure, and is practically the same as that of the graphite bar type (1 ton). The small 100 kg graphite bar furnace compares still more favourable with the induction heating type.

Consumption of Lining Material.

In the 100 kg drum furnace, 300 kg corundum cement was used for first lining which lasted 250 operations; with 3 more repairs, using 50 kg corundum cement at a time, another 150 operations could be performed. Thus altogether 450 kg corundum cement was used up in 400 operations, i.e., 10.2 kg/ton of steel.

Not so favourable is the result with the 1 ton open hearth furnace type. The hearth requires 900 kg tamping material for the first 280 operations and another 3×250 kg. for the next 600 operations. Altogether 1650 kg. for 880 operations which is equivalent to 1.7 kg/ton of steel.

The walls of the hearth furnace were lined with sillimanite brick at the beginning, but this was soon changed to corundum cement. With 700 kg. of cement 100 operations could be performed, which is 6.36 kg/ton of steel.

The furnace arch requires 450 kg. for 450 operations, i.e., 0.91 kg/ton of steel. Further 1500 kg. corundum cement is needed for lining and repair of all other parts (9.1 kg/ton of steel), so that altogether 18.1 kg/ton of steel is required.

The total graphite consumption amounts to 2.1 kg. and 2.7 kg. per ton of steel for the 100 kg. and the 1 ton furnace respectively. This compares favourably with 6.8 kg. per ton of steel needed in an electric arc furnace.

The consumption in cooling water is about 1-1.5 m^3/hr. and 4 m^3/hr. respectively for the two types of furnaces. However, the same water can be made to circulate in the cooling system by means of a pump, and then the actual fresh water consumption becomes very small.

Economy and Possibility of Further Development.

Although it is not yet possible to draw final conclusions about the economy of graphite-bar furnaces, there are a few points which indicate a satisfactory prospect. In the first place, there will be a considerable saving in wages, as such furnaces require but very little attention. Also the initial costs will be low as no expensive transformers or condensers are required, as is the case for induction furnaces. Wastage is another factor in favour of graphite bar heating, and space economy is also not to be overlooked. All these apply to both the open hearth and drum type of furnace, falling out more favourably for the latter type.

The problem of lining, however, is not yet solved to full satisfaction; if quartz or ganister could be used instead of corundum cement, the costs of lining, too, could be brought in line with the other economical features of such plants.

This type of heating permits the use of a high temperature, low viscosity slag and further developments are therefore indicated. With basic lining, thorough de-sulphurising and de-phosphorising of the charge should be possible, provided that the graphite bars withstand the strong chemical attack of the slag (lime-fluorspar for instance.) The drum type of boiler especially, has a great future in the steel industry, if such furnaces can be designed for greater capacity.

CONDITIONING OF AIR SUPPLY FOR COMBUSTION IN FURNACES

By Dr. Ing. Wilhelm Gumz. (From *Feuerungstechnik*, Vol. 30, No. 1, January, 1942, pp. 1-4).

The air supplied to grate firing systems is controlled corresponding to the local demand of the combustion zones. The main air stream reaches the zone needing most cooling, no air is conveyed to localities where air current might cause disturbances, and is throttled where only a moderate supply of air is required. This subdivision of the grate into zones, and what is even more important, their separation from each other, has produced important developments in grate firing systems during the last 20 years which are manifested in increased specific output and improved efficiency of combustion.

The process of combustion in the fuel bed and the fire box above it has been established by comprehensive tests, and the fact should be emphasised that, even during the combustion of a fuel poor in gas, a considerable quantity of gas is developed in the fire bed, which together with the more volatile constituents of the fuel should be burnt in the fire box. The problem is thus reduced to providing a proper gas-air mixture in the fire box, which can be best solved by arranging for a secondary air current under a pressure head of about 3-400 mm. w.g. The efficiency of combustion is greatly affected by the secondary air current which permits the use of a much lower fire box, thus reducing the heat losses through radiation.

The increasing demand for energy, the limited coal supplies, and the high cost of energy, all necessitate still further improvements in efficiency and output.

As an example, let us examine a moving grate and its limitation of loading. With a good quality, standard fuel, the load is limited by (a) the speed of combustion which, for a given grate dimension, has an optimum value corresponding to a certain load; (b) the stability of the fuel layer; and (c) the maximum permissible dimensions of the grate. As further influencing factors, the speed of ignition of the fuel, and clinker formation are to be considered. The principal drawback of grate firing compared with oil or gas firing systems is the limitation of air temperature. Good fuel economy would demand the use of an air pre-heater connected after the feed water heater. This would permit far-going exhaust heat utilisation which would raise the overall efficiency of combustion. Therefore, means must be sought to enable the use of higher air temperatures also for grate firing systems without endangering the operational safety.

Whenever combustion takes place in a fuel bed there are two zones to be distinguished. A short oxydation zone, and directly adjoining a reduction zone where the products of combustion from the oxydation zone combine with carbon to form a combustible mixture. This process is common to both the fuel layer in grate firing systems and in gas producers, but whereas in the latter it is endeavoured to promote it by every means, the relatively thin fuel bed, in the first case, does not favour it. The highest temperature and hence the zone where clinker is most readily formed is the oxydation zone. If now the velocity of the air current is increased, the combustion is speeded up without increasing the dimensions of the oxydation zone. Even under the most unfavourable conditions the turbulence will increase the rate of combustion sufficiently not to affect the oxydation zone. Hence a very effective means of increasing the grate output is given and its upper limit is the stability of the fuel bed with respect to the fast air current. With high quality fuels, however, the usual grate loading is still far from the limit of fuel-bed stability. Although some small size fuel particles are being carried into the fire box by the air current these are usually separated out and carried back to the fuel bed and burnt.

As an increase of the grate area is not feasible, moreover being expensive since the boiler must be made larger too, the only sound method of increasing the output of a boiler plant is by increasing the velocity of the air current, which is identical with increasing the specific output of the grate area.

With the compression of greater heat output into smaller space and the accompanying increase of air temperature, heavier clinker formation is, of course, to be expected. To counteract this, therefore, some modification of the grate firing system is essential. An excellent example is given by the gas producing technique. A very common method used by every gas engineer is to saturate the air used for gas production at 50-60 °C. The first advantage of this method is to produce additional CO and H_2 gases by the reaction of the water vapour with the carbon, and to increase the heating value of the gas. But the secondary task of saturation is none the less important: to prevent clinker formation in the oxydation zones. No sooner such troubles start, the water content in the air is increased somewhat, and the proper working conditions are restored at once. In some cases pure oxygen is used for gas generation, and even then it is possible to control the oxydation and reduction zones and, of course, the clinker formation. Gas production is hence a full proof of the safety of the method. It seems, therefore, that the problem is simplified to arrange for a method by which the air supply can be saturated with water vapour, and then, even under unfavourable conditions, full control of combustion and clinker formation will be attained. This method requires some explanation.

The combustion in the solid phase is based on a transport of oxygen in the air to the surface of the solid fuel. This transportation of oxygen, even as a purely physical process, determines the rate of combustion. During the travel, the oxygen molecules meet combustible

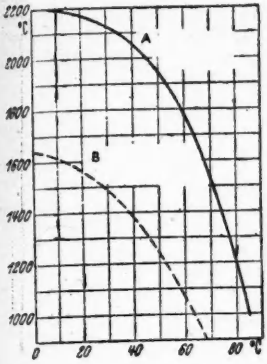


Fig. 1. Saturation temperature of air. A=Maximum temperature. B=Probable temperature.

gases, CO and H_2, formed at the fuel surface, and burn them to CO and H_20 in a plane below the fuel surface. If water vapour is contained by the air, this will largely contribute to the formation of combustible gases at the fuel surface. This means that the zone of maximum temperature lies below the fuel surface, in the plane where the gases are oxidised by the air current. If, now, the temperature of combustion is calculated which would take place at various air humidity, the figures obtained, even at high saturation temperature, would be much too high for the safe combustion of an ash containing fuel. The fact that at say 60 °C saturation temperature, a fuel containing ash, the melting point of which is about 1250 °C, can be burnt, shows that combustion is not taking place wholly in the solid phase, but that the existing temperature is not more than ≤ 1000-1100 °C, or probably even much less (Fig. 1). Thus saturation of the air charge can be utilized also for grate firing.

Just the same as excess air is to be avoided, excess of water vapour might also be harmful, and can be tolerated only at localities where it will be able to bring about the required effect. This, then, suggests that the grate area be subdivided not only into zones of different air supply (pressure), but also the saturation temperature of each zone should be individually determined, according to the demand. Fig. 2 shows, schematically, how this could be done. (A) is a moving grate to which hot air, preheated at (B), is supplied through the main trunk (C). Individual tubings, branching off from (C), convey the air to the zones, five in this particular case. (E) is a fresh air ventilator supplying cold air through (F) and adjustable valves (G) to the individual air duets (D). The water is supplied through the tube (H) and the nozzles (J). (K) is a valve regulating the air quantity to each zone, while the tube (L) supplies air through the secondary air current valves (M), to the fire box above the fuel bed. With this scheme it is possible to regulate the pressure (quantity) of air, the temperature, water content of each zone and the secondary air current.

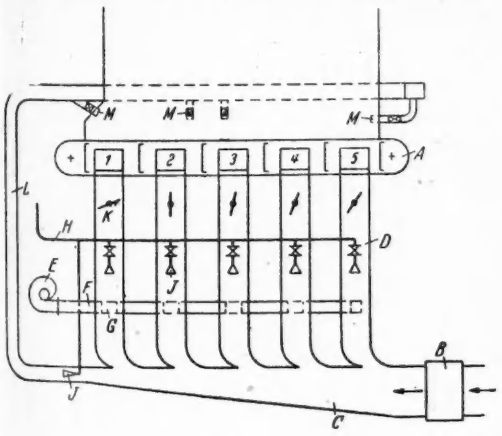


Fig. 2

As an example the first zone, where mainly ignition of the fuel is taking place, is supplied with dry, hot air. At this point namely the cold, probably damp fuel is first to be brought to its ignition temperature, and, therefore, very high temperatures may be allowed to exist, and even the pre-heated air temperature is not sufficiently high to ignite the fuel rapidly. Improvements could be achieved by adding hot flue gases to the air charge.

In the second zone ignition of the fuel will probably be complete, and towards the end of the second zone the highest temperatures are reached. To the second and third zone, therefore, ample air is supplied to speed up combustion and to cool the grate. The water vapour is also increased and this will have the effect that only small size clinker is formed which will not interfere with the complete combustion of the fuel, or the perviousness of the fuel bed to the air current. The high vapour content helps combustion also by transferring a considerable portion of combustion into the fire box from the fuel bed.

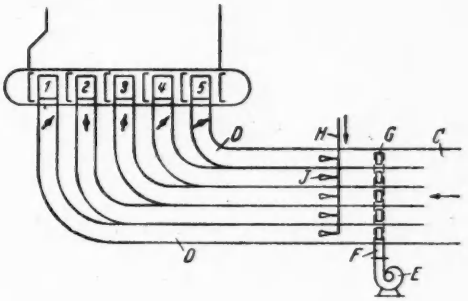


Fig. 3

In the fourth and fifth zone, corresponding to the gradually increasing clinker formation, the air is throttled, the saturation temperature reduced so as to arrange a suitable air temperature for the smaller demand of grate cooling.

The conditioning of the air currents or the individual zones was assumed so far to be uniform within one zone. To obtain this in practice, it is necessary to provide a moderately long path for the air current to allow ample time for mixing. As shown by the schematic arrangement in Fig. 3, the air ducts are extended for this purpose.

Air conditioning will, as follows from the above, increase the gas formation in the fuel bed, and to deal with these gases the secondary air current must be also increased. But increased combustion over the fuel bed will not affect the load of the grate, and it is thus possible, under otherwise identical conditions, to attain a maximum specific output per unit grate area, since a great part of the combustion will be transferred from the fuel bed into the space above and there will be no need for a larger boiler plant. Further, the saturation of the air permits much higher air temperatures as before, which is a great improvement of the economy of energy pro-

duction. The regulation of the saturation temperature in the individual zones is very simple. By regulating the fresh air supply through (G) and the quantity of water injected through (J) [Figs. 2 and 3] the whole control is well in hand. Naturally, for such saturation purposes there is no need to use fresh or exhaust steam, which can be better utilized for pre-heating feed water and air. Generally the hot air temperature will suffice to evaporate the necessary amount of water injected which might be slightly warmed by the residual heat content of the exhaust gases after the pre-heaters.

Air conditioning becomes thus most economical. If the specific grate output of a gas producer is compared with that of a furnace, the comparison will fall out well in favour of the gas producer, showing that there is still ample possibility for further improvement of method and efficiency. At the same time there is no need to operate with such high pressures as in gas producers. Gas producer practice also shows that it is quite possible to avoid clinker troubles so that this fact alone would justify the use of air conditioning. The costs of air conditioning should be very moderate indeed.

ELECTRIC DYNAMOMETERS FOR ENGINE TESTING

By R. H. WRIGHT, Westinghouse Electric and Manufacturing Co. (From *Westinghouse Engineer*, Vol. 2, No. 2, May, 1942, pp. 39-42).

FOR the accurate determination of engine performance at all speeds and loads nothing is as satisfactory as the electric dynamometer. In the case of rotating machines, as gasoline engines, their function is the determination of turning effort or torque. This effort, measured on an ordinary weight scale as force in pounds at some distance or lever arm from the centre of rotation, multiplied by lever arm and by speed of rotation, gives the work done by the engine.

Mechanical Brakes.—The Prony brake, the classic example of a dynamometer, consists of an adjustable friction brake on the shaft of the machine being tested. To the brake is attached an arm resting on a scale, so that the tendency for the arm to turn is measured in pounds. The difficulties of this type of brake are the variations of the friction and the heat developed in the brake. Water brakes provide a better means of dissipating heat than the friction brake, but are not suitable for the exacting demands of the modern engine laboratory.

The Cradled Dynamometer.—The electric dynamometer solves, in addition to making possible the determination of engine torque, three other problems of engine testing. It provides a convenient means of applying any desired constant load, acts as an engine starter, and drives the engine for light load and special tests. The efficiency of a power-transmission device, such as a gear or fluid drive, can be determined by the use of two electric dynamometers, one to measure power input, the other power output.

The cradled dynamometer is now the most common form. It is a motor or generator, which differs mechanically from an ordinary generator only in that the stator instead of being fixed to the foundations is supported in bearings so that it can turn through a small arc. Turning is restrained by a lever arm that bears on a scale. The scale readings measure the force with which the stator tries to turn, are not affected by electrical losses, and only minutely by the mechanical losses (friction and windage) in the dynamometer. Therefore, the torques measured are, within fine limits, the net torques delivered to or exerted by the dynamometer.

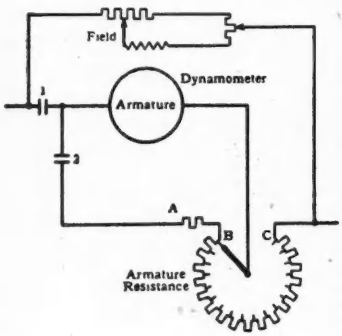


Fig. 1. Fundamental diagram of the electric dynamometer.

The adjustable armature resistance is designed for continuous duty. When the dynamometer is used for starting the engine, the armature is connected to the resistance at B. Contactor 1 and 2 are closed to form a potentiometer circuit. Speed control is obtained by adjusting the field. For heavy starting contactor 2 is opened and 1 closed. For feed-back loading the armature is connected to point C.

The armature and shaft are supported in two bracket bearings attached to the stator. The brackets and stator in turn are supported in two antifriction trunnion ball bearings so that the stator can rotate within the limits of its mechanical stops. The maximum angular movement is only a few degrees. Under this condition the bearing race tends to wear in one spot. This wear increases static friction and causes loss of accuracy. To overcome this tendency means for rotating occasionally the trunnion bearings are sometimes provided. These mechanisms can be operated manually (for dynamometers of 150 H.P. or smaller ones) or by a motor (for large dynamometers used for laboratory tests on aircraft engines). Dynamometers with motor driven rotators, which turn the bearings continuously at low speed are more accurate, because the running friction is less than static friction. The two trunnion bearings are rotated in opposite directions so as to counterbalance the effect of bearing drag.

For many purposes the dynamometer acts as a motor drawing power from the supply line and driving the engine instead of absorbing power, e.g., for starting the engine, for tests which have to be made on engines running idle, for independently testing accessories, such as superchargers, etc.

The cradled dynamometer can be made to operate either on D.C. or A.C., but for general-purpose they are made for D.C. However, when large amounts of power are required at high speed, say above 2000 r.p.m., it may be desirable to use an A.C. machine in order to avoid commutators at high peripheral speed. A motor-generator can be used, when necessary, to feed the electric energy produced in the dynamometer into the distribution system.

Direct-current cradled dynamometers for tests on automobile engines (seldom over 200 H.P.) are generally operated from a constant voltage source. If the capacity of this source is not sufficient, the power absorbed by the dynamometers is dissipated in resistances (Fig. 1). However, as for larger engines large resistance banks would be necessary and a considerable waste of energy would result, it is now common practice to feed this power back into the plant D.C. system. The means for doing this is also indicated in Fig. 1. In many cases it is best to use a separate variable-voltage generator for each dynamometer as shown in Fig. 2.

The Eddy-Current Brake.

The Eddy-current brake, a recent development in dynamometers, absorbs, just like the Prony brake or the water brake, energy from an external rotating source,

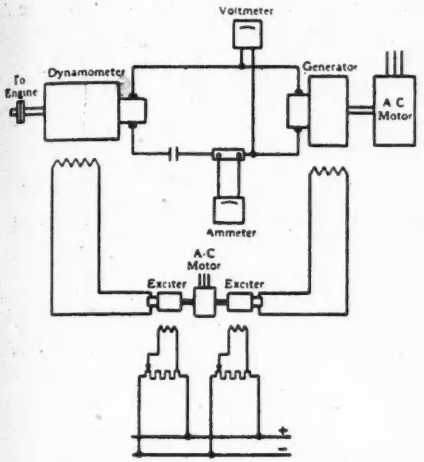


Fig. 2. Instead of controlling the large field currents of the generator and in the dynamometer with rheostats, each field is supplied from a separate exciter in which the voltage is adjustable with a small resistor.

and the reaction of its stator is measured to determine the engine torque. The most common form of eddy-current brake is shown in Fig. 3. The rotor is made of steel and has teeth in its periphery, the stator has no teeth and no winding for collecting current. Field coil and magnetic flux is indicated in the figure. Rotation of the rotor produces eddy-currents in the stator, that provide the load for the external driving machine. The heat produced by the losses is carried off by water circulated through the stator, which is cradled, the torque

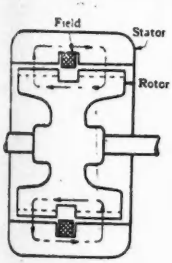


Fig. 3. Currents induced in the rotor of the eddy-current brake result in opposing torque that can be used to load large engines.

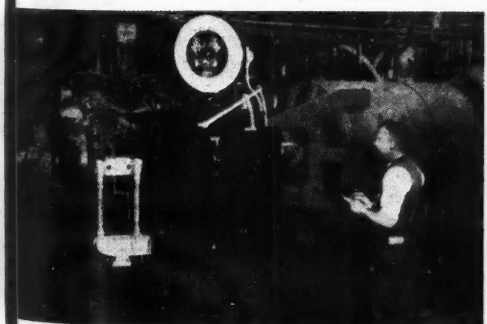


Fig. 4. This combination dynamometer for high-power Pratt & Whitney aero-engines has a total absorption capacity of 4000 H.P.

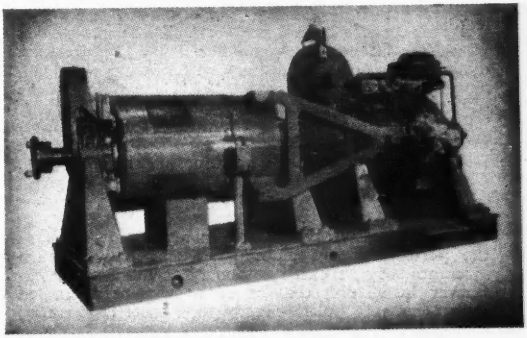


Fig. 5. Rear view of the combination dynamometer shows how the eddy-current brake is fastened to the D.C. machine to form one unit.

being measured in the conventional way. Large eddy-current absorption dynamometers for loading large aero-engines are provided with an electrical stabilizing device. A belted compound-wound exciter supplying a separate field winding produces a voltage varying approximately as the square of the speed. By this means any tendency for the engine speed to rise is checked by the increased braking torque of the dynamometer and hunting is reduced to a minimum.

These brakes can be built for higher speeds in small capacities and can be made for a greater range of speed at high capacities than other form of electric dynamometer. But they cannot deliver power to the engine, and the energy produced by the engine is a total loss.

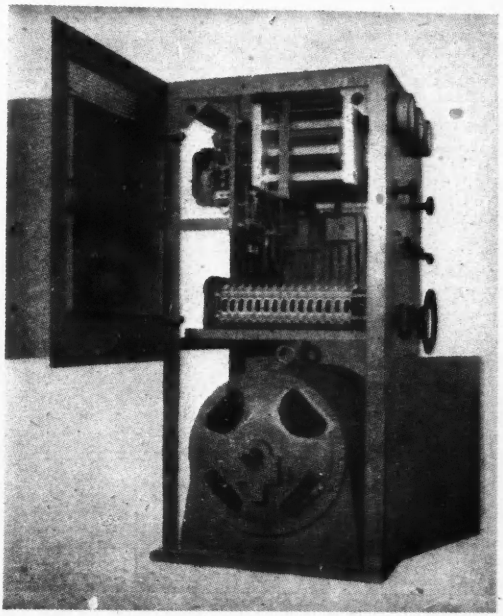


Fig. 6. A stationary dynamometer such as this, complete with control, is used for routine testing of truck and tractor engine.

Combination Dynamometer.

As the cost of a D.C. dynamometer for a complete test of a large aircraft engine in prohibitive, combination dynamometers have been designed consisting of a D.C. machine and an eddy-current brake. The stator frames of both units are mechanically connected. The D.C. unit provides the necessary motoring effort and assists in holding the speed constant, when in parallel with a D.C. energy source. Such machines are shown in Figs. 4 and 5.

Chassis Type Dynamometers.

So called chassis type dynamometers are used to check the performance of automobiles and trucks. Such machines may be either stationary or mobile. A stationary installation consists of a slow-speed cradled dynamometer coupled directly to a shaft that carries two pulleys about 48 inches in diameter. The rear wheels of the car or truck rest on the pulleys and drive the dynamometer by friction. With this type of dynamometer, the friction from engine to rear wheels and the net horsepower available at the wheels can be determined. A complete laboratory installation may include a small wind tunnel to simulate actual road conditions.

Stationary Dynamometers.

In addition to the problem of development testing there is the fast-growing one of production testing. Stationary dynamometers (Fig. 6) are used in large numbers for routine production tests of automobile, truck and tractor engines. It is not unusual to have from twenty to one hundred units in one installation.

A stationary dynamometer is really only a standard adjustable speed d.c. machine, which serves either as a motor or a generator. An engine coming from the assembly line is first driven idle to wear in the bearings and piston rings. Then it is allowed to fire and to drive the dynamometer as a generator. The energy generated is fed into the D.C. bus. The frame is not cradled, so the output is measured electrically. As the losses of the generator are known, this is, in general, satisfactory for production testing.

TRAPPING DUST ELECTRICALLY

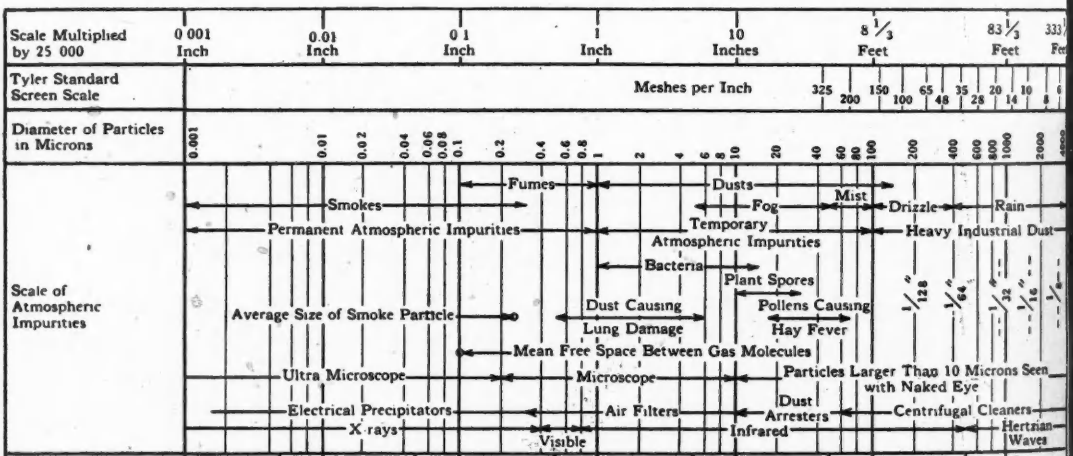
(From *Westinghouse Engineer*, Vol. 2, No. 2, May, 1942, pp. 46-50).

SOME figures may illustrate the importance of the dust-problem. Typical counts in large cities like New York and Chicago run from one to three million particles per cubic foot. In Pittsburg a blanket of dust, 1950 tons per square mile, gradually settles each month throughout the heating season.

In a day a person breathes about 34 pounds of air—over five times as much as the combined weight of food and water consumed daily. In breathing that much air the average city dweller takes into his lungs each week a teaspoonful of dirt.

The economic loss caused by smoke is enormous.

One reason, why, perhaps, relatively little has been done about the cleaning of air used for ventilation, is that we are dealing with the invisible. For each visible dust particle, there are tens of thousands below the limits of visibility, i.e., below about 10 microns in diameter. A micron is 1/1000 of a mm. The lower extent of their size is unknown, because even with the ultra-microscope, particles less than 0.001 micron cannot be counted with trustworthy results. As shown in the table below, if dust particles were multi-



Rate of Settling in Fpm for Spheres of Density 1 at 70°F		0	0	0	0	0 00007 = 3/64"	0.002 = 1.4" per hr	0.007 = 5" per hr	0.148	0.592	14.8	59.2	555	790
Number of Particles in 1 Cu Ft	Air Containing 0 0006 Grains of Impurities per Cu Ft (Density = 1)	75×10^{15}	60×10^{13}	75×10^{12}	60×10^{10}	75×10^{9}	60×10^{7}	75×10^{6}	600 000	75 000	600	75	0.6	0.075
Surface Area in Square Inches		≅ 365 = 2 53 sq ft	73 0	≅ 36 5 = 1/4 sq ft	7.3	≅ 3 65 = 1.9 in. sq	0.73	≅ 0.365 = 5/8 in sq	0 073	≅ 0 0365 = 3/16 in. sq	0.0073	≅ 0.00365 = 1/16 in. sq	0.00073	0.000365

Based, in part, on information from W. C. Frank and from *Chemical and Metallurgical Engineering*, Vol. 45 p 133

plied 25,000 times in size, the relative range in size of objects that air cleaners must handle extends from particles no larger than the diameter of a human hair to a ball over 300 feet in diameter, in which could be placed a 30-storey building. Particles smaller than 0.3 micron, including cigarette smoke, never settle out by gravity alone. Except as they are removed by rain, air currents, etc., they remain permanently suspended articles, invisible to the eye, but important to health of man and to the size of his cleaning bill.

The Principle of Electrostatic Air Cleaning.

The first observations of electrical precipitation of charged particles to a surface oppositely charged have been made by Hohlfield of Germany in 1824. Sir Oliver Lodge applied the principle successfully in a lead smelter in 1884. But electrical precipitation of dust did not become widely practical until 1906, when Dr. Cottrell, who had worked with Lodge, brought out the precipitator that bears his name. In the Cottrell system alternating current stepped up to 50,000 to 100,000 volts and rectified by a rotating machine. The negative terminal of the rectifier is connected to a heavy wire stretched between vertical plates spaced 10 or 12 inches apart and of positive polarity. Corona discharges start between wire and plates. A dust particle becomes negatively charged, is attracted by the plates and remains on them by mechanical and electrostatic adhesion.

Whereas the Cottrell precipitator has been widely used for industrial plants, especially to precipitate smoke from chimneys of power plants and factories, it has not been used for ventilating systems, because at the high voltages used ozone is produced in such quantities that the air becomes too toxic for human consumption.

In 1937 a new type of electrical precipitator appeared, known as the Precipitron, suitable to ventilating systems. It uses smaller ionizing wires and closer spacings of the plates. The smaller the wire the lower the D.C. voltage needed to cause ionization and resulting charging of dust particles. The Precipitron uses a tungsten wire

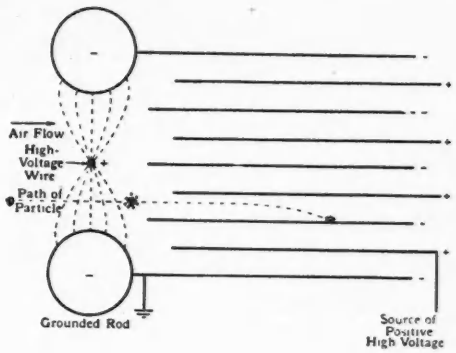


Fig. 1. In the electric air cleaner a particle is positively charged so that in the collector it is drawn from the air by negatively charged plates.

only five mils in diameter. It requires an ionizing potential of about 12,000 volts, $\frac{1}{8}$ to $\frac{1}{10}$ as much as in the Cottrell type. This means smaller, less expensive equipment and the absence of nearly any ozone. Also contributing to extremely low ozone formation is the fact that in the Precipitron type of cleaner the ionizing wire is made positive instead of negative. By a slight sacrifice in efficiency a reduction of the order of ten to one in the production of ozone is achieved. With ionization by 12,000 volt from a positive wire the ozone formed is only one part in a hundred million parts of air, or equivalent to that caused by sunlight in ordinary air.

The wires are held between tubes oppositely charged. A dust particle as it passes between a wire and a tube is charged (in about 0.1 second) and is swept on into the collector section, as shown in Fig. 1, where it is

Fig. 2. Electric air cleaning units being assembled for removing dust from cooling air for steel-mill motors.

attracted by the negative (grounded) plate. Thus ionization and collection are separated in the Precipitron. This principle in the design made the new system economical for ventilating systems by the great reduction in size and cost of the unit, which resulted from this arrangement.

The Precipitron-type of electrostatic air cleaner is made in cell form, each 36 inches high by 8 inches wide, which includes an ionizing and a collecting chamber (Fig. 2). Cells are arranged as required to accommodate the amount of air circulated. Each cell has a rating of 600 cubic feet of air per minute for 90% cleaning efficiency or 750 cfm. for 85% efficiency. Energy is supplied by a power pack, which comprises a high voltage transformer, vacuum tube rectifier tubes and capacitors to smooth out the pulsating D.C. voltage. One size of power pack can supply energy for twelve 36 inch cells. It has an energy consumption of 110 watts. A larger pack can accommodate 50 cells, with an energy consumption of 380 watts (power factor 0.75-0.80).

Advantages of Electrostatic Air Cleaning.

Particles from the smallest detectable with microscopes up to visible ones are removed by the precipitator. The cleaner offers virtually no resistance to the air flow. It requires no replaceable elements, except vacuum tubes, which have a rated life of 4000 hours, roughly six months. Ionizing wires usually last about two years, the collector plates require periodic cleaning (washing, drying and re-oiling).

Many Jobs for Electrical Air Cleaning.

The first large-scale use of the Precipitron was for the removal of dust from the ventilating air of public buildings, such as offices, stores, restaurants. One of the first office buildings to use an electrostatic precipitator is the Field Building of Chicago (17 groups of cells, 275,000 cubic feet of air per min., installed in 1937).

The interior of a store had been annually repainted at a cost of $4000. An electrostatic air cleaner was installed at a cost of $7000 and annual repainting became unnecessary.

Many manufacturing operations are so precise, that even a microscopic film of dust impairs the product. Therefore, many aircraft-engine factories now electrically clean the air to rooms where the bearings are lapped and where the final inspection and assembly are done. Likewise in the grinding of optical glass atmospheric dust cannot be tolerated. To reduce the maintenance expenses of electrical machines, electrostatic precipitators have been installed in the re-circulating cooling-air ducts of some large synchronous condensers. Because of the large quantities of metallic dust about steel and aluminium mills, and because of the large numbers of heavy current D.C. machines present, many mills electrically clean the air for machine ventilation. In several such plants over 100,000 cubic feet of air per min. are thus cleaned, and in one large mill, a million.

It is probable that after the war the electrostatic air cleaner will have an important place in the ventilating of the private home. The electrostatic cleaner removes air-borne pollen and brings relief to most hay-fever sufferers. Another function is the removal of bacteria and mold spores from the air.

THE FATIGUE STRENGTH OF CHROMIUM PLATED DURALUMIN

By A. BEERWALD. (From *Luftfahrtforschung*, Vol. 10, No. 10, October, 1941, pp. 368-371).

THE dual purpose of metallic coatings is: Protection of the base metal from corrosion, and improvement of the general appearance of the article. It is, therefore, usually sufficient to apply a coating 0.01 mm. thick, whereby the mechanical properties of the coating metal are of little or no importance.

Opposed to this, chromium plating is applied mainly because of its mechanically desirable properties, such as hardness, resistance to wear and smoothness of surface. The thickness of chromium plating is correspondingly many times that of other metallic coatings, being usually between 0.03 and 0.1 mms.

Quite apart from this discrimination, the electroplating of chromium, too, differs from the usual electroplating methods. The chromic acid bath is of moderate concentration, and a comparatively high current density, about 40 amps/dm², is used in conjunction with an elevated temperature. The valency of chromium in the acid is 6 and has to be reduced to the mono-valent form, i.e., pure metallic state. It is, therefore, to be expected that it will pass through a number of phases and as a consequence, in the lower valency form, chromium compounds form a film on the cathode thus preventing complete reduction to metallic chromium. To overcome this difficulty 1% sulphuric acid must be added to the bath.

Another difficulty is encountered owing to the strongly negative potential of depositing chromium. This effects liberation of hydrogen which takes up the bulk of the current available and only about 15% of the current is utilized for chromium deposition. The liberated hydrogen reacts with chromium, and if the base metal is iron or steel, also with this, and renders the article brittle. The remedy for this defect is heat treatment at 150-200 °C which drives out the hydrogen from both the chromium layer and the base metal.

An inspection of the chromium surface reveals a net of fine hair cracks; heat treatment has the effect of strengthening these cracks. But according to the author, there is no reason for suspecting hydrogen to be responsible for the origination of the cracks, nor for their strengthening during heat treatment.

Comprehensive investigation was carried out by H. Wiegand to establish the fatigue strength of chromium plated steel parts. The present article describes experiments and gives results of similar tests made on chromium plated Duralumin articles. The necessary conditions for chromium plating duralumin (and light metals in general) have been investigated by the author in the research laboratories of the D.V.L. For better understanding of the following sections they are briefly summarized here.

It has been known for some time that prior to chromium plating the light metal must be exposed to a corroding medium in order to produce a rough surface. This is essential to ensure proper cohesion between the chromium layer and the base metal, otherwise the chromium coating could be peeled off even by hand. The effect of the corroding medium varies not only with the alloy to be plated, but, using the same base metal, even with its structure. The aim is to produce a close and uniform surface roughness.

For alloys containing copper an etching process was developed which makes the roughness independent of the metallic structure. It consists of etching in NaOH for 30 secs. at 60 °C, followed by etching in concentrated $NiCl_2$ for 40 secs. to which a small quantity of boric acid is added. The nickel coating is then removed in nitric acid bath and chromium plating follows then in the usual manner.

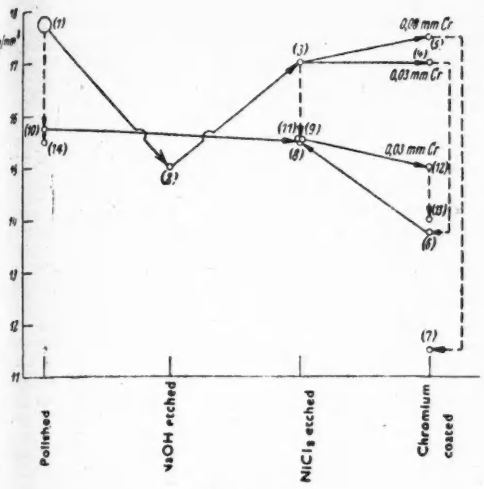


Fig. 1

Experiments.

The fatigue strength in bending of duralumin bars of 6 mm. diameter was tested up to 20×10^6 repetitions. Mean values were calculated from 5 to 10 tests.

During the study of the fatigue strength of chromium plated duralumin certain differences must be considered compared to chromium plated steel. Heat treatment, at about 200 °C, has no effect on steel, but it might provoke a change of strength in duralumin. It seems further probable that roughening of the duralumin surface, which is essential for proper binding of the chromium layer, is also a modifying factor for the strength of chromium plated duralumin. Therefore, to clarify this problem, the investigations included testing of etched but uncoated duralumin bars.

The test results are given in Table I. In two cases the etching was only in NaOH and in $NiCl_2$ respectively (test 15 and 17). As in these instances proper cohesion of chromium to the bars could not be achieved, a thinner layer, 0.01 mm. thick, was only applied.

Fig. 1 shows graphically the results; the arrows and bracketed numbers refer to the order in which various treatments followed in succession.

The first remarkable observation was the marked drop in fatigue strength after etching in NaOH (test 2); the subsequent etching in $NiCl_2$ restores the strength almost to the original value (test 3). The most probable explanation to this phenomenon is that the second treatment provides a very close and uniform roughening of the duralumin surface, so that peak stresses cannot occur at the roots of the individual surface projections. In other words, this treatment, in effect, is equivalent to a small reduction of cross sectional area of the bar. If the sample is etched only in NaOH, the roughness is neither close nor uniform and peak stresses may be responsible for early fatigue failures.

Chromium plating after etching in NaOH and $NiCl_2$ has no influence upon the fatigue strength of duralumin (test 4). The same observation was made when the plating followed etching in NaOH or zincate solution (test 2 and 15, 16 and 17 respectively).

Heat treatment, on the other hand, at 180 °C for 2 hours reduces the strength considerably (tests 6 and 7). This becomes more marked with increasing thickness of plating, and therefore, it can be concluded that the presence of chromium is an influencing factor in regard to this phenomenon. A further indication to the correctness of this assumption is given by the fact that if the chromium layer is dissolved off in a sulphuric acid bath, the strength is increased again. As, however, it can never be restored to the original value, it shows that heat treatment has also affected the duralumin itself.

If one starts off from heat treated samples, the following can be observed

Etching in $NiCl_2$ is of no effect for the same reason as given above (test 11). Chromium plating reduces the strength figure slightly (test 12). Subsequent heat treatment brings about a further reduction of strength (test 13), but in this case the reason for it rests solely with the chromium layer as a second heat treatment is of no further consequence.

Conclusion.

It is evident, from the foregoing, that several factors are mutually responsible for the decrease of fatigue strength of chromium plated duralumin. Duralumin is affected, in the first place, by the etching process,

TABLE I.

Test	Surface Treatment	Thickness of coating mm.	Heat Treatment	Fatigue strength in kg/mm²	Decrease of fatigue strength %
1	Polished	—	—	17.75	—
2	Etched in NaOH	—	—	15.00	15.5
3	Etched in NaOh + $NiCl_2$	—	—	17.00	4.3
4	Chromium plated	0.03	—	17.00	4.3
5	Chromium plated	0.08	—	17.50	1.5
6	Chromium plated	0.03	2 hr. at 180°	13.70	22.5
7	Chromium plated	0.08	2 h. at 180°	11.50	35.0
8	Chromium dissolved off in H_2SO^4	(0.03)	2 h. at 180°	15.50	13.0
9	Etched in NaOH + $NiCl_2$	—	2 h. at 180°	15.5	13.0
10	Polished	—	2 h. at 180°	15.7	11.0
11	Test 10 etched in NaOH + $NiCl_2$	—	—	15.5	13.0
12	Test 10 chromium plated	0.03	—	15.0	15.5
13	Test 10 chromium plated	0.03	2 h. at 180°	14.0	21.0
14	Test 10 polished	—	2 h. at 180°	15.5	13.0
15	Etched in NaOH and chromium plated	0.01	—	15.0	15.5
16	Etched in zincate	—	—	16.2	8.5
17	As before and chromium plated	0.01	—	15.7	11.5

whereby it should be noted that the strength is least decreased if the roughness is close and uniform ; luckily this is also a desirable condition for satisfactory cohesion between the chromium layer and the base metal.

The application of the chromium layer in itself has no effect on the strength. This is rather a peculiar feature, as one would expect an adverse influence from the fine cracks in the chromium surface. The decrease of strength produced by the subsequent heat treatment exceeds the extent which could be attributed to the effect of heat treatment upon duralumin. The reason for this, however, is not quite clear as yet, since the enlargement of the cracks as a result of heat treatment could hardly be responsible for a decrease in strength so rapid as for instance in tests 5 and 7.

An explanation is suggested by the author which is based upon the consideration of the cohesive force between chromium and duralumin. When the base metal is steel or iron the binding is much stronger between the two metals, and in this case the cracks would have a more marked effect, even without heat treatment, than in the case of light metals where one cannot talk of an atomic binding. Therefore, it is possible that owing to heat treatment a more intimate binding occurs in a mechanical manner whence the effect of cracks becomes more pronounced. Furthermore, the expansion of duralumin during heat treatment (about 0.1%) must be also considered, as it might be responsible for an increase in stress between chromium layer and the duralumin and for further strengthening of the binding.

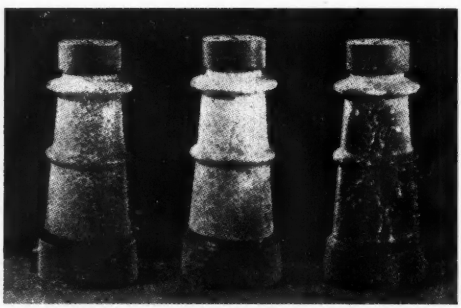
From a more practical point of view, much less importance need to be attributed to heat treatment when the base metal concerned is duralumin or other light alloy, than when it is steel or iron. In the latter case, heat treatment is essential to deprive the sample of its brittleness caused by the hydrogen absorption, while duralumin is not affected by hydrogen, and small amounts in the chromium layer are of no practical importance. There only remains the danger of decrease in strength if the application of the chromium plated duralumin part is such as to allow heating by friction or otherwise.

VAPORISATION BY HEAVY CURRENT ARCS

By W. KAUFMANN, Berlin. (From *Elektrotechnische Zeitschrift* [*E.T.Z.*], Vol. 63, No. 13-14, April 9th, 1942, p. 162).

ARCS generally occur in consequence of disturbances. They often cause severe damage to the switch-plant. Considerable quantities of metal may be melted where the arc starts. The consumption of metal by the burning arc amounts to 5 to 10 g per kA sec. Most of this metal is vaporised and forms dense clouds in the switch plant. It precipitates on cold objects. First of all insulators may be endangered by such metal vapours. It is an old experience, that the soot produced by oil fires in switches, deposits chiefly on live insulators. Since such deposits may become the origin of flashovers, the plant must be thoroughly cleaned before supply is restored.

When copper in switches began to be replaced by aluminium, it was feared that the deposits of aluminium evaporated by an arc would cause the same difficulties as the soot of oil fires. However, no metallic deposit is formed by such aluminium vapours, as the vaporised aluminium immediately oxidises in the air, and aluminium oxide, Al_2O_3, is a bad conductor.



a b c

Fig. 1. Metal deposits on insulators produced by an arc of 1.5 kA and 5 secs.

(a) Insulator in 15 cm distance from aluminium electrodes
(b) „ 30 cm „ „ „ „
(c) „ 15 cm „ „ copper electrodes

In order to throw more light on this question, which, of course, is of great importance for in-door switches, a few simple tests have been made. Some 20 kV bus insulators were placed in various distances from an arc burning between two aluminium electrodes 5 cm. apart. An arc of 2000 ampere burning during 5 sec. showed the following effect. The aluminium electrodes produced a dense white cloud, which filled the whole test room. The insulator next to the arc (15 cm.) was covered on the side facing the arc with a dense net of little molten metal drops (Fig. 1a). Only a few such metal drops reached the insulator No. 2 placed in a distance of 30 cm. (Fig. 1b). The insulator No. 3, which was shadowed by insulator No. 1 and the insulator No. 4 at 60 cm. distance showed no such drops. All insulators were covered on their whole surface with a rather dense coating of white aluminium oxide.

The four insulators behaved very differently when tested with A.-C. high voltage. On the insulator covered with metal drops (No. 1) the first discharges between the metal drops burnt into the porcelain occurred at 20 kV, when the insulator was dry. These discharges developed to a continuous row of sparks at 30 kV and to a complete arc-over at higher voltage. With all other insulators, including No. 2 which had been placed at a distance of only 30 cm. from the arc, the arc-over occurred at only a slightly lower voltage than with normal, clean insulators. This shows that the oxide coating has no bad influence on the dry flash-over. Moistening the insulators with water vapour caused the difference between the insulators which had been exposed to the arc and clean insulators to disappear. According to the degree of moisture, the arc-over voltage on both the clean and the oxide coated insulators decreased from 81 to approximately 50 kV.

The tests were then repeated with an arc between copper electrodes. On the insulator at a distance of 15 cm., a dense yellowish-brown to deep-olive-coloured deposit condensed on the side facing the arc. This deposit included sporadic metallic drops (Fig. 1c). But the high voltage test had the astonishing result, that flash-over did not occur with a voltage below 70 kV. This shows that the quantity and the size of the metallic drops on the porcelain surface have a decisive influence on the arc-over voltage.

SUMMARY.

Only the insulators nearest to the arc are damaged in a higher degree by metal drops from an arc between aluminium electrodes than from an arc between copper electrodes. When the current is very high and the arc has burnt a long time, the metallic aluminium drops may cover such a great part of the porcelain surface that the arc-over voltage becomes lower than the rated voltage. But the tests showed, for aluminium and for copper electrodes, that only a few drops of the molten metal reached the surface of insulators which were placed in a greater distance from the arc, for example 30 cm. or more, or which were protected from the arc by cell partitions. In switches of the usual type there is no danger that metal drops may be thrown from an arc on apparatus in a neighbouring cell. As the deposit of the metal oxide does not reduce the insulating properties of the surface of the insulators, whether in dry or in moist state, it follows from these tests, that aluminium is not disadvantageous as compared with copper.

CORROSION FAILURES

By FRITZ BORSIG. (From *Stahl und Eisen*, Vol. 62, No. 9, February, 1942, pp. 174-182).

CORROSION as a primary cause of general breakdown is as frequent as it is important. In the following the research work carried out by the Allianz Insurance Co. (Technical Department) on corrosion and its prevention will be discussed.

Wet steam being a frequent cause of corrosion, steam engines are naturally the most important group of machinery exposed to such damage. During standby periods of turbines, steam may leak through badly fitting valves and condenses on the cold turbine surfaces. Water vapour and oxygen from the atmosphere, too, will find a way to the interior of turbine plants. As a result, corrosion of the turbine blading may occur, as shown in Fig. 1. The trailing edge of the blades is completely destroyed and the blades are covered with a thick layer of rust, and at some points corrosion has penetrated completely through the blading material.

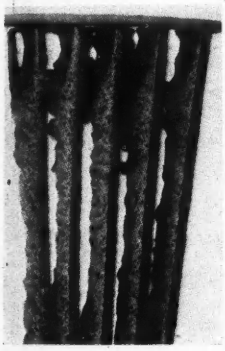


Fig. 1

A more interesting type of corrosion is shown in Fig. 2. The guide blades of the turbine are a plain steel while the nozzle plate is of stainless iron. Owing to imperfect welding a small crack was left between the two segments and gland or leakage steam could condense in it initiating corrosion. The rust formed in the crevice may be responsible for more serious troubles, and if fragments of the nozzle plate get into the blade top clearance annulus the turbine blading might be completely destroyed. The rust deposit on the blades alone might cause a marked drop in efficiency or else cavities caused by corrosion constitute weak spots, thereby causing failure of the blading.

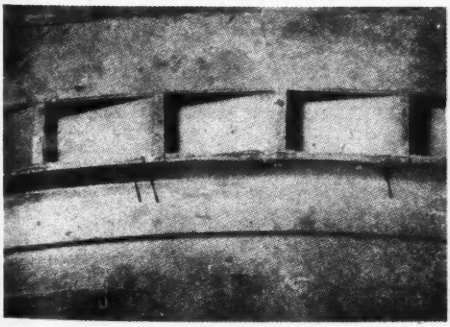


Fig. 2

A distinctly different type of corrosion can be observed in Fig. 3. A thick layer of rust is formed on the metal, but as a discrimination to the previous type of corrosion, the rust layer is covered with abrasion marks. Moreover the metal beneath the rust layer is usually sound. From investigations on a large number of similar cases, the most probable explanation to this phenomenon is that it is only an accumulation of rust deposit, the corrosion producing it actually being located at some other part of the unit.

Reverting now to the question of corrosion caused by leakage steam, comprehensive tests were carried out by the Technical Department to find out how far this can be prevented by applying a protective oil film on the exposed surfaces.

The apparatus used, Fig. 4, consisted of a tower of about 2 m. height, the top part being subdivided into 6 equal compartments each holding a test piece in suspension. A container placed below the open end of the tower was heated and the steam so generated rose to the top of the tower, flowing past the test samples and was finally drawn out at the top of the tower. The corrosive action of the arrangement was very powerful.

Some of the test pieces in suspension were coated with an oil film, by dipping them into oil, others were left clean and dry. Before and after the test the samples were carefully weighed and the oil film removed. The tests have revealed that the oil film is an efficient protection against corrosion, especially if renewed at intervals. It was further found that emulsive oils are better than ordinary mineral or paraffin oils. This can be seen from Fig. 5, showing the result with various classes of oil on 5% Ni. Steel and cast iron samples.

Apart from steam and oxygen, corrosion in steam plants is also caused by the chemical action of salts and gases carried by the steam. It is a known fact that salts in the feed water might be carried over by the steam,

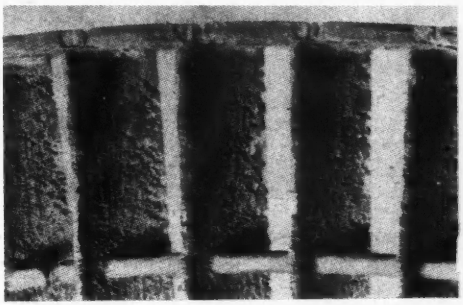


Fig. 3

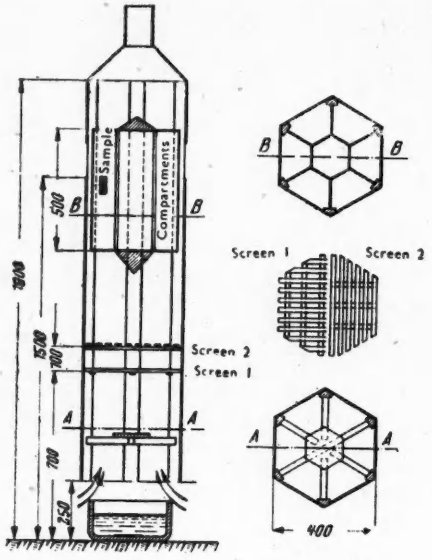


Fig. 4

either in suspension or, as in the case of alkali compounds, at high pressure and temperature through evaporation. As long as these substances are alkalies, e.g., sodium silicate, there is no danger of corrosion and the only troubles are due to deformation of the blade profiles caused by the deposit or due to abrasion in the cylinders. Altogether different is the case with potassium compounds, as for instance potassium sulphate. Even more dangerous is the effect of gases carried over by the steam. Corrosion caused by carbonic acid in the steam has been observed more than once and in some instances even sulphuretted hydrogen. The latter was also found to be responsible for the rust formations which were carried and deposited on the blades (Fig. 3).

Fig. 6 shows a section of nickel packing ring taken from a Ljungstrom turbine. The ring shows quite

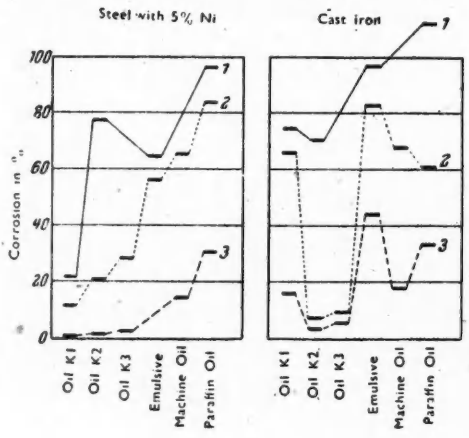


Fig. 5

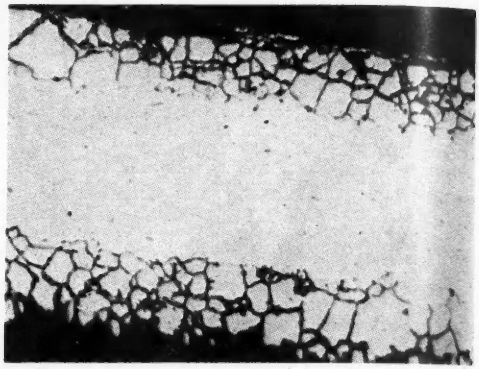


Fig. 6

clearly inter-crystalline corrosion which could not have been caused by steam alone ; more likely, it was caused by the mutual effect of steam and sulphuretted hydrogen. This type of corrosion makes the metal very brittle, and fragments from it cause serious trouble.

Water, too, is a strong corrosive agent, especially in condensers, condenser tubes, economisers, boiler plants, etc. A particularly rare case of corrosion caused by the condensate on a turbine is shown in Fig. 7. The drain pipe was clogged and consequently the condensate had accumulated in the bottom of the turbine casing. Eventually, the height of the water level became so high that the turbine blades were partly immersed in the water and corroded.

In the presence of oxygen, corrosion can occur not only in warm and soft water but also in installations in which salty water at low temperature is circulating. Figs. 8 and 9 show two sections of a tube from a brine refrigerator plant, heavily attacked by corrosion. The appearance of the corrosion and the condition of operation of the plant suggests that corrosion was caused by oxygen. Owing to a peculiarity of the plant, namely, that air was being forced into the brine in large quantities, oxygen concentration could take place, especially as the low temperature of the brine promotes the solubility of oxygen. The slow heating up of the brine separates out the oxygen at some other part of the pipe and together with the chlorides in the brine started corrosion, which was particularly heavy in the copper tubes. The rust coating shown in Fig. 12 contains an appreciable amount of copper. At the same time a

N.B.—Steam and hydrogen sulphate would be sulphuric acid.

Big. 7

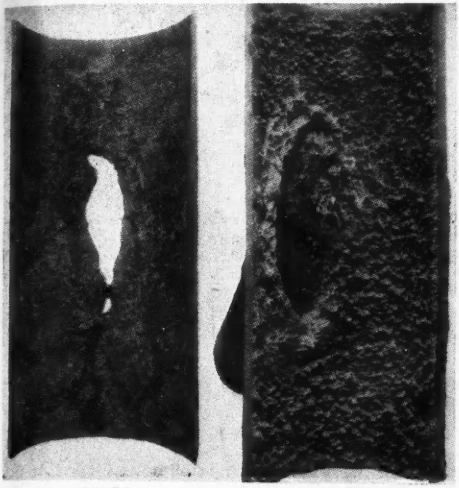
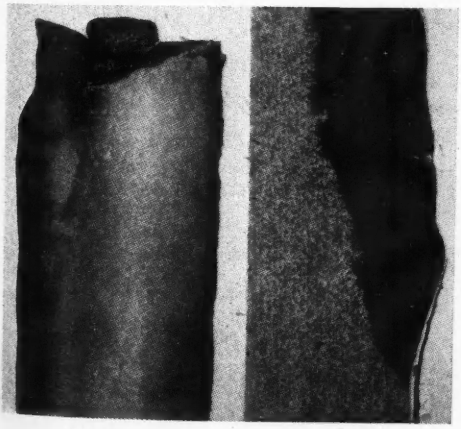


Fig. 8 Fig. 9

constant decrease of the p_H value of brine was noticeable which should have remained constant at 7. At first it was endeavoured to maintain steady conditions by adding a small amount of potassium hydroxide to the brine; however, without success. To clarify this problem, the effect of brine in the presence of oxygen on mild steel and copper was investigated and also the effect on the p_H value. As was expected, strong corrosion was eminent with both metals; furthermore it was found that the p_H value of the solution gradually changed and tended to a constant value of 4.5-5. The presence of oxygen had little effect, except for accelerating the process. Below this equilibrium value (4.5-5) of p_H, corrosion is less marked with higher p_H value and becomes steady at 4.5 to 5. This means in other words that corrosion is heavier the smaller the p_H value and remains at a steady intensity above 4.5. The plant has been operating at p_H 5 for several months, without increasing the degree of corrosion: technical changes of the plant are contemplated to eliminate



Eig. 10 Fig. 11

corrosion altogether. Recent investigations have also shown that corrosion takes place on stainless steels; no details of this phenomenon are, however, known.

Electrolytic corrosion or corrosion caused by local current formation was also observed in a number of cases. A remarkable case, only recorded once, is shown in Figs. 10 and 11. The figures show a turbine blade made of 5% Ni. steel with a pure nickel plating. The shroud ring was made of a non-corrosive 14.5% Cr. steel. During the assembling of this blading, the plating became detached from the blade at the rivet head and water collected in the recess so formed. Electrolytic corrosion then destroyed the blade.

Another noteworthy case of electrolytic corrosion was reported to have taken place in a fractured ship propeller shaft. Small currents produced by the friction between shaft and gun metal bearing started corrosion, which eventually, by weakening the shaft, caused fatigue failure. Electric currents from outside source have not been found to cause corrosion, in the few cases where this was intimated the external source of current could either not be found or other causes, too, for corrosion existed making it impossible to establish the fact that corrosion was due to external currents.

Stress-corrosion is also frequently the cause of failure of a machine part. In steam boilers tearing of rivet holes is reported even nowadays, but this question is not yet fully clarified as the salts from the boiler water are also playing an important part.

Fig. 12

Two more cases of corrosion should be mentioned which do not fit in the groups discussed so far. The first case, Fig. 12, is a nest of tubes taken from an exhaust gas pre-heater connected to a turbine. 4 preheaters are employed, which are connected in series and each one being lower in position compared to the preceding unit. Strong corrosion attack can be seen, which actually penetrated through the tubes. At first glance they appear to be due to abrasion, but a metallographic examination reveals that it is corrosion caused either by acids or electrolytically. The most striking feature is the location of the corrosion, namely in the bend of the tube connecting the first nest of tubes with the rest. For this reason it is more likely that it is an electrolytical corrosion and not caused by oxygen and carbonic acid. In a similar case the suction valves for de-aeration were repositioned at the bottom of the preheater with the result that corrosion was eliminated.

Finally, corrosion on a petrol distillation plant is described. The tube made of mild steel, taken from a heat exchanger, showed corrosion on the outside and inside of the tubes. The probable explanation of this corrosion is the action of sulphides (ammonium sulphides) which are present in small quantities in the oil.

ELECTRO-ACOUSTIC DETONATION MEASUREMENT

By Dipl. Ing. Paul Funck. (From *ATZ, Automobiltechnische Zeitschrift*, Vol. 45, No. 2, January, 1942, pp. 21-25).

The basis of electro-acoustic detonation measurement is the sound produced by the pressure wave of a detonating combustion. The first publication on the recording and defining this sound wave originated in 1936, subsequent developments then advanced the method not only to show detonation, but also to measure its intensity from initiation to peak value. This, then, provides a means of examining the performance of a particular engine with regard to detonation to a far greater degree of accuracy than was possible before.

This method requires no special modification to the engine and experiments can be carried out on single and multi-cylinder engines, on the test bench as well as in actual operation.

Method.

A piezo-electric sound detector, well protected against ambient sound effects and vibration, is fitted on to the engine block or otherwise suitable place on the engine. The transformer converts the sound waves reaching the detector into electric potential waves, which, after being suitably intensified, are made visible by a cathode ray oscillograph. If the flow of electron impulses is so controlled as to one cycle corresponding to half the engine speed (to the engine speed with 2 stroke engines) a standing trace of the wave is obtained on the screen of the oscillograph, corresponding to the consecutive pressure waves generated during combustion. The amplitude of deflection of the electron wave above and below the mean line is a measure of the recorded sound wave.

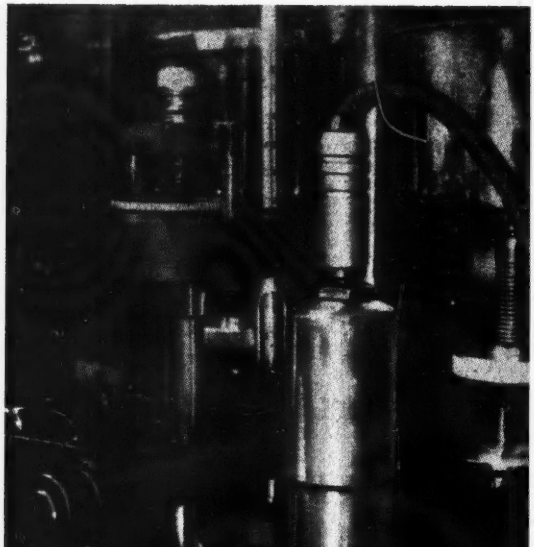


Fig. 1

Detonation Recording Apparatus.

In a detonating engine, the sound wave is a complexity of mutually overlapping sound waves of various frequencies. Nevertheless, detonation is accompanied by a characteristic sound "pinking" which can be selected out from the concert of other noises even by a layman. In order, however, to detect the detonation wave also on the screen of the oscillograph, the detona-

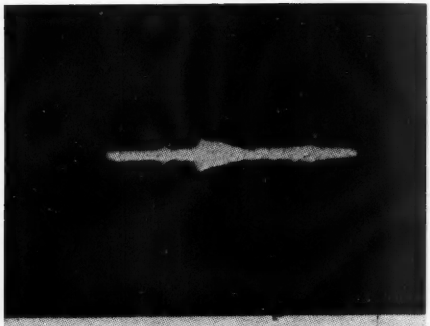


Fig. 2

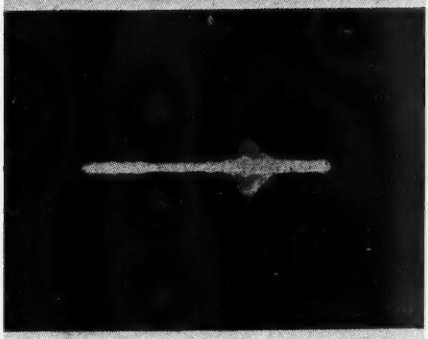


Fig. 3

Fig. 4

tion waves must be distinctly raised above those due to normal combustion. The task is then to oppress the unimportant sound waves into a narrow band and to enlarge the sound of detonation. This is done by the amplifier and the selector. The difference in amplitude between ordinary sound waves and those due to detonation is thus a measure of the perfectness of the apparatus, and with newer designs the ratio of amplitudes is in the vicinity of 37:1.

Experiments on Single Cylinder Engines.

The method of electro-acoustic detonation measurement is clearly indicated in the following. Fig. 1 shows the sound transmitter fixed on to the cylinder head of a single cylinder I.C. engine, and it can be seen that no modification of the engine itself is needed, the apparatus being simply fixed to a cylinder head bolt by an intermediate fish plate and a nut.

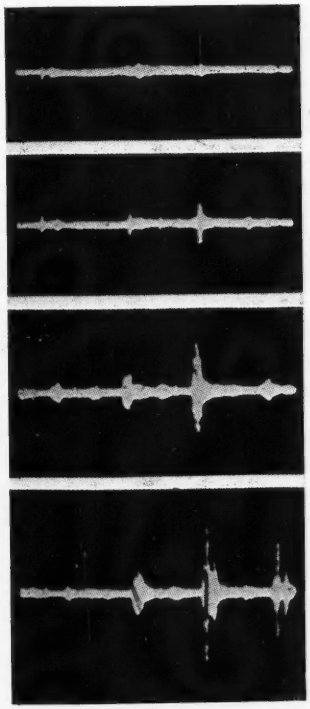


Fig. 5

Figs. 2, 3 and 4 are the recorded sound waves at different compression ratios of the engine. Of these, the first shows smooth running. The first small deflection is due to the ignition spark ; this is followed by the noise of normal combustion. With detonating combustion, which is produced by increasing the compression ratio, the second deflection is very much enlarged. Fig. 3 shows "pinking" detonation, Fig. 4 intensive detonation. (Note that the path of electrons is from left to right).

To measure the intensity of detonation, the potentials are measured by a millivoltmeter. If these measurements are recorded for a specific fuel in dependance of the compression ratio, a detonation curve, Fig. 5, is obtained. A comparison between detonation curves of various fuels provides a means to the determination of fuel characteristics with regard to detonation far beyond that possible by Octane No. measurements.

Experiments on Multi-Cylinder Engines.

It was found from tests that by using a single apparatus it is still possible to undertake detonation measurements on multi-cylinder engines. This, then, is the main function of electro-acoustic measurement.

Fig. 5 is a photograph taken from the screen of an oscillograph when testing a four cylinder engine. Detonation, in this case, was caused by advancing the ignition. As each cylinder has one working stroke during one cycle of the diagram, the deflections due to detonation for each cylinder appear in the order of their firing (1, 3, 4, 2 in this case). The ignition is marked on the left hand side of the diagram as a small deflection. The large deflection on the right hand side is due to detonation. A very interesting picture is (b) Fig. 5, which corresponds to the onset of detonation, that is, detonation which is not yet audible.

The method also provides an easy means of recording the diagrams for later study by photographing individual or a series of consecutive diagrams. This permits not only a careful examination of detonation waves, but also reveals some important and interesting features. Such is, for instance, the case in Fig. 6, where in cylinder 4, detonation is gradually increasing through four working strokes and is decreasing afterwards. That such phenomena is taking place was suspected before, but could not be ascertained.

Electro-acoustic detonation measurements are also easy to undertake on engines when actually in operation. In this way the behaviour of the fuel under varying conditions, such as operation on a level road, on a gradient, during acceleration, etc., can be easily studied. This permits general conclusions to be drawn as regards a particular grade of fuel, and at the same time reveals irregular behaviour of the individual cylinders —a point of considerable practical importance.

Finally, it should be mentioned that this method of detonation measurement is equally well applicable to aero-engines, the same method being employed.

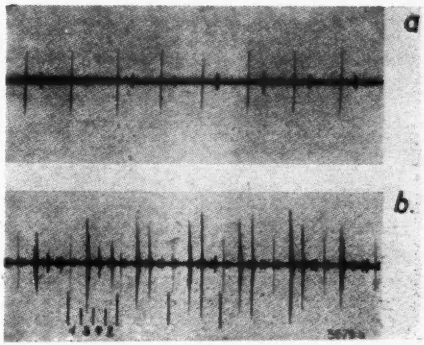


Fig. 6

PHOTO-ELECTRIC SAFETY COUPLING

By J. KUHN. (From *Elektrotechnische Zeitschrift* [*E.T.Z.*], Vol. 63, Nos. 17-18, May 7th, 1942, p. 210).

THE two halves, a and b, of the coupling (Fig. 1) are torsionally displaced in dependence on the torque transmitted. The discs c fixed on the two halves of the coupling have uniformly distributed slots d. The adjustment of the discs on the coupling is such that, when the coupling is running idle, the slots of one disc are covered by the other disc and the light beam of the light source (e) cannot fall on the photo-electric cell (e'). When the coupling is loaded, the relative displacement of its two halves brings the slots of the two discs more and more in coincidence, so that a light beam, increasing in intensity with the amount of the torque transmitted, will reach the photo-electric cell. The current of the cell, increased by an amplifier, feeds a relay, which interrupts the circuit of the driving motor when the torque transmitted by the coupling or the load of the driving motor exceeds a certain limit. The adjusted slots can also be such, that the light beam passes freely in the state of no load on the coupling, and is cut when the maximum admissible displacement of the halves of the coupling, i.e., the maximum torque, is attained.

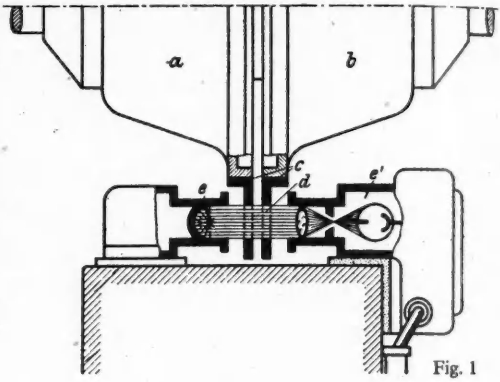


Fig. 1

DEVELOPMENT OF HIGH SPEED COAL-DUST ENGINES IN JAPAN

By H. WAHL. (From *Zeitschrift des VDI*, Vol. 85, Nos. 51/52, December, 1941, p. 989).

JAPAN'S interest in the development of the coal-dust engines is based upon her mineral wealth and fuel supply. Whilst German experiments were carried out with low speed, stationary engines, the Siro Nakazaki has developed a six-cylinder automobile engine, of 110 mm. bore, 110 mm. stroke, 50/75 H.P. at 1300/2000 r.p.m.

Coal-dust of a heating value of 7500 Kcal/kg is delivered to the engine from a container at the rear of the car by means of a conveyor (worm), the speed of which is adjustable in accordance with the engine power. Valve (a) controls the coal admission, which, together with the air is metered into the pre-combustion chamber (b) during the suction stroke. During the subsequent compression stroke, hot air streams into the chamber (b) from the cylinder (e) and raises the temperature of the coal dust almost to its self-ignition point, when a sparking plug (c) ignites the charge. The highly compressed gas-dust mixture expands now into an annular intermediate chamber (d) and then enters the main combustion chamber (e) through tangential slots. Combustion is completed in the combustion chamber (e) under the action of strong turbulence.

The fuel consumption is claimed to be 2800 Kcal/B.H.P. per hour, and the mechanical efficiency is 67%.

To reduce wear of the cylinder walls and piston rings, and to provide effective scavenging of the combustion chambers, the piston head is extended upward by half the stroke length. As this extension is of a smaller diameter than the cylinder, an annular space (f) is provided, into which scavenging air is blown at the end of both the suction stroke and the expansion stroke through the scavenge parts (g). All parts subject to wear and abrasion are made easily exchangeable.

The original article does not make it clear, how, with the chosen type of plunger, the contamination of the oil in the crankcase can be avoided. Experience gained from several German experimental stations is not encouraging as regards to contamination of oil.

Every technical development starts from the primitive, passes through the complicated to the expedient and simple; the present solution, by utilizing data available from German research, has certainly evaded the first stage, but is well within the boundaries of the second stage. Before it could enter into competition with the liquid or gas driven engine, this Japanese dust engine needs further development with respect to weight, price, economy and safety of operation.

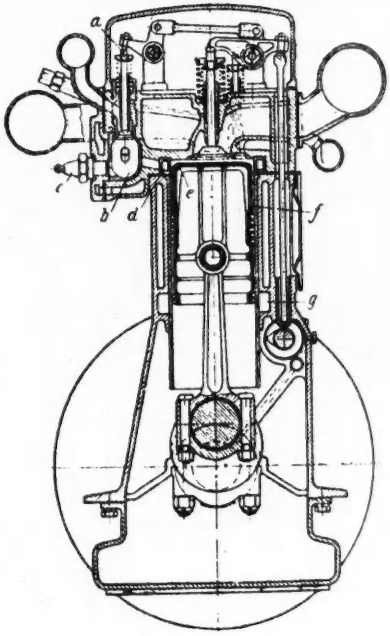


Fig. 1

SAVING MATERIAL AND TIME IN AIRCRAFT PRODUCTION

By L. ENGELHARD. (From *Zeitschrift des VDI*, Vol. 85, Nos. 41/42, October, 1941, p. 840).

SAVING in material can often be effected, if, for instance, welding is employed instead of machining from the full. Welding compares favourably even with drop forging. Principal improvements in design, too, can bring about saving in material, time of machining and assembling. Often, small changes in details lead to results.

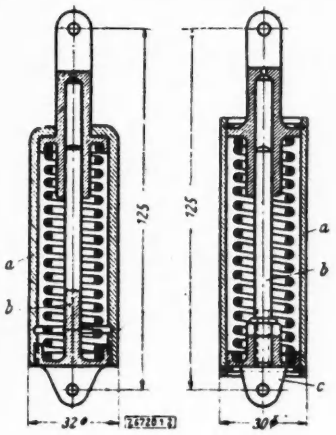


Fig. 1 Fig. 2

To illustrate this, from numerous examples, the case of a shock-absorber is selected and will be discussed. In the original design (Fig. 1) the waste of material by machining the parts a and b is obvious. For these two parts, 0.36 kg of light alloy was needed. By using two internal type Seeger circlips, part a in Fig. 1 can be replaced by the tube a in Fig. 2. Part b in Fig. 1 can be divided into two pieces, b and c in Fig. 2, making the total amount of material required for a, b and c according to Fig. 2, 0.09 kg only. Thus, saving of 75% of the material was effected.

The time of machining of a and b according to Fig. 1 was 50 mins., for a, b and c according to Fig. 2, 25 mins. only. The saving in machining time amounts to 50%.

Although such savings appear to be insignificant, on a mass produced Dornier the saving given below was achieved. Furthermore, 250 kg bronze-free light alloy was used per aircraft as a substitute material, resulting in a considerable saving of copper.

SAVING IN MATERIAL/AIRCRAFT.

Iron	25.4 kg
Copper	8.4 kg
Bronze	4.2 kg

SAVING IN PRODUCTION TIME/AIRCRAFT.

Maching time	24 hours
Welding	23 hours
General	28 hours
	Total 75 hours

HIPERSIL, AN IMPROVED MAGNETIC STEEL

(From *Electrical Engineering*, Vol. 60, No. 6, June, 1941, p. 260).

HIPERSIL, an improved magnetic silicon steel, having a magnetic saturation value approximately one third greater than conventional silicon steel, has been announced by the Westinghouse Electric and Manufacturing Company.

Hipersil (high-permeability silicon steel) reaches this higher saturation at the same magnetizing force as conventional silicon steel. Improved properties have been achieved by specially developed rolling procedure and heat treatment, which produce in the final product a preferred orientation of crystal lattice. The material must be used in such a way, that its "grain" is aligned with the direction of the magnetic field; if the grain is at right angles to the field, the material is inferior to ordinary silicon steel.

Core losses in transformers in which Hipersil is being used are not greater than they are in transformers using conventional steels. By use of the new material in distribution transformers size and weight could be reduced by 25%. Copper losses could be reduced too, and short-time overload capacity increased. Magnetostriction of the new material is reduced so that even at the increased flux density, at which the material operates, no increase in transformer noise results, as compared with transformers having cores of ordinary silicon steel.

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- NEW EQUIPMENT
- BOOKS AND CATALOGUES
- BUSINESS CHANGES
- PERSONAL
- NOTES

NEW EQUIPMENT

A NEW GEAR HOBBING MACHINE.

THE Gear Hobbing Machine (Fig. 1) designed and built by Messrs. Craven Brothers (Manchester), Limited, Reddish, Stockport, includes some new features and several patented devices. The improvements meet the demand for extremely accurate gearing. The machine is shown in the illustration with the long tangential slide for worm wheels, but it is made also with the ordinary hob slide for dealing with spur and helical gears.

The bed is of inclined box construction, widened out under the front of the column and dropped back behind. The guides carrying the table are prismatic and the inner surface is inclined so as to shoot the cuttings and lubricant out through the side into the sump.

The table is 5′ diameter and integral with it is the master wheel. This is totally enclosed in a cradle permitting the lower surface of the table to be immersed in oil. The master worm and worm wheel also run in oil, the teeth of the wheel being of special design to enable the worm to draw in the lubricant between the contacting teeth. The worm wheel is of extreme accuracy, having been carefully checked and corrected by a unique "Craven" process to reduce its tooth-to-tooth error and accumulated error to very fine limits. The methods adopted for the measurement and correction of master gearing, whether creep or non-creep, are of such a nature as to eliminate entirely the possibility of variation of gauge readings due to the human element. In other words, the measuring bridge gauge itself—which reads to ·0001″—gives exactly the same reading independently of the man operating it. The correcting machine is automatic, its correcting device checking electrically to ·0001″, and it maintains the correct form of tooth both of the worm and spur gears.

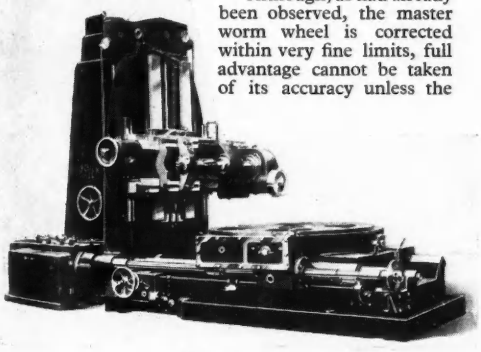

Fig. 1

Although, as had already been observed, the master worm wheel is corrected within very fine limits, full advantage cannot be taken of its accuracy unless the worm itself is also accurate. In other words, although the master wheel is important, the worm is more so. This was recognised by the late Sir Charles Parsons, and resulted in his introduction of the creeping table to produce quiet-running high-speed turbine reduction gearing.

The machine is not fitted with the creeping table, but the worm unit has been produced to the same limits of accuracy required for the production of high-speed gearing. The worm unit itself is shown in Fig. 2, and can be mounted up complete and tested before being put into the cradle. The worm is solid with its shaft to avoid the possibility of distortion in driving the shaft into a bored worm. It will be seen that the worm is driven by one of two gears on the worm shaft. These two gears mesh with two other gears on a lower shaft running along the bed which, in the ordinary type of Gear Hobbing Machine, is usually the worm shaft.

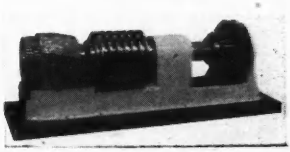

Fig. 2

It will be seen, therefore, that there is a change of gearing from this shaft on to the worm shaft. The purpose of this is to relieve the long shaft of heavy torque when cutting a large gear and to prevent it running at too great a speed when cutting a small gear, as in the first case the large wheel on the worm shaft will be in mesh with the small pinion on the long shaft, and in the second case the small wheel on the worm shaft will be in mesh with the large wheel on the long shaft. This is a feature which has been patented recently by Messrs. Craven Brothers. The worm itself is hardened, ground, lapped and polished and made to very fine limits of accuracy; the end movement is reduced to less than .0001″. Adjustment between the bearings is taken out by means of adjustable nuts in which there is no possibility of slack back. The handle for changing over the drive to the worm will be seen on the side of the table in Fig. 1.

The column is of box construction and contains the balance-weight for the cross slide. It is spread out at the base and recessed in order to embrace partially the table when cutting smaller wheels and pinions. This avoids an undue permanent overhang of the hob slide and at the same time gives much greater stability to the column itself.

The top of the column contains the mechanism which drives down to the feed screw and also to the shaft which provides the cross traverse motion when using the tangential feed for worm wheel hobbing.

The hob slide is of the tangential type used usually

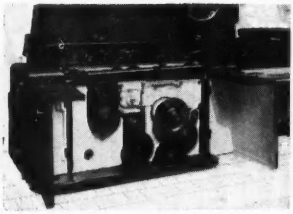

Fig 3

for producing worm wheels by means of taper hob or travelling fly cutter. This slide is so constructed that it can be set to any angle and the tangential feed used at that angle, as both the drive and the feed motion come through the swivel centre.

The drive from the swivel centre is by means of a train of spur gears running on ball journals down to the worm and worm wheel, the latter of which is mounted on the hob spindle. This worm and worm wheel are totally enclosed, running in oil, and of rapid pitch, the worm shaft carrying at the end a heavy fly-wheel which is dynamically balanced.

The slide is indexed for setting for cutting worm wheels at an angle or for cutting helical gears, but in addition a clinometer is supplied with the machine in order to facilitate extremely fine setting.

The Gear Box is of novel construction, as it contains the whole of the complicated mechanism necessary for a machine of this nature. This mechanism consists of the main dividing gears, the prime number gears, the two differential gears, one for the prime number gears and the other for the spiral angle, a nest of feed gears giving four feeds instantly obtainable, pick-off gears to extend the range of the feed gears, quick traverse and reverse gearing. The whole of the mechanism in this box is either running in oil or spray lubricated.

The feed, dividing, prime gears and spiralling gears which have to be changed are shown respectively in Figs. 3 and 4. These are lubricated by cascade actuated by separate pump.

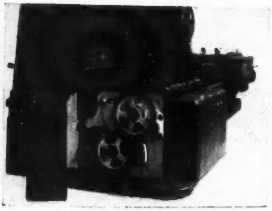

Fig. 4

The principal characteristics of the machine are as follows:—

It will cut any number of teeth including primes, up to 600, without special change wheels. This can be done at any angle and at any rate of feed within the capacity of the machine, the feed can be stopped, started, changed or reversed whilst the machine is running, without disturbing the relation between the work and the hob.

The table can be rotated rapidly by means of independent gearing, separate entirely from the change wheels. Quick traverse motion is applied in either direction to the transverse slide up and down the column, to the hob slide along the transverse slide, to the table towards and away from the column and to the rotation of the table in either direction.

On the gear box also are the push-button stations controlling the two motors. The main driving motor is 10 H.P. and is arranged to start an inch in either direction and stop. The quick traverse motor is also reversible and controlled by push buttons.

The hob speeds are controlled by pick-off gears carried on the motor gear box on the opposite side of the machine from that shown in Fig. 1. This box provides the necessary range of speeds, and in addition there is

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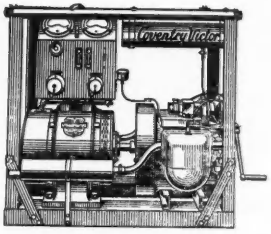

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also a change of gearing in the cross slide which permits a high ratio to be used when cutting gears of heavy pitch and a low ratio to be used when cutting gears of lighter pitch with small hobs. This is a great improvement in this class of machine as it avoids extreme speeds of the driving shafts and gearing.

Provision is made in order that smoked-glass or similar tests can be taken whilst the machine is cutting.

These tests are of extreme importance, particularly when the machine is required for accurate high-speed work, as the exact relation between the movement of the worm and the table and between the movement of the hob and the table must be established within satisfactorily fine limits before the work is proceeded with.

The principal dimensions of the machine are as follows :—

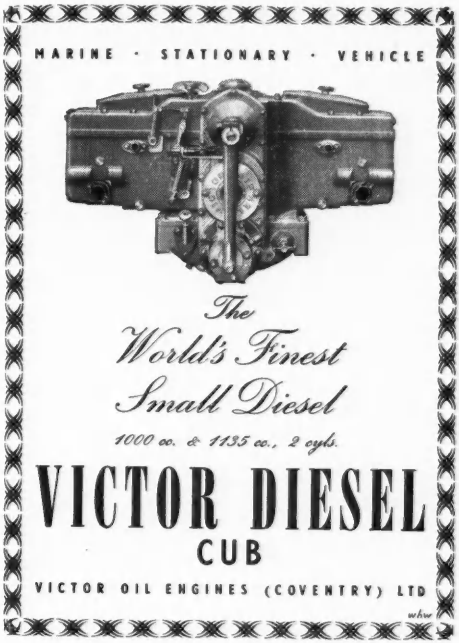
Maximum diameter of gear	7'6".
Minimum diameter of gear	4".
Maximum width	2'10".
Maximum pitch	1 D.P.
Diameter of hole in table	12".
Maximum diameter of hob	10".
Maximum length of hob	12".

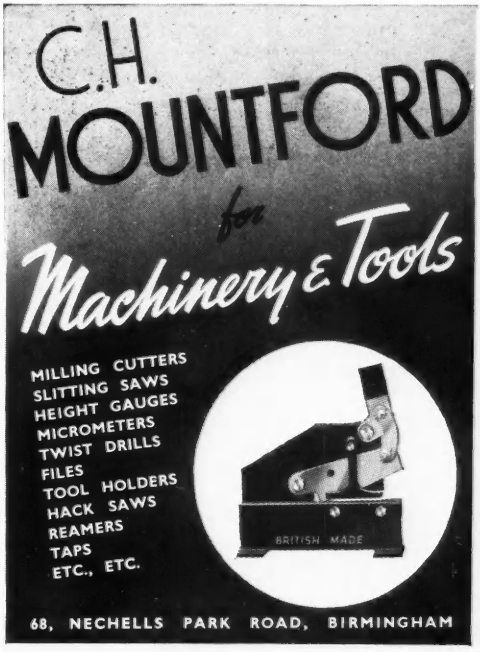
It may be of interest to state that Messrs. Craven Brothers (Manchester), Limited, have in manufacture the largest and heaviest Gear Hobbing Machine ever made. It is for producing the highest class of turbine reduction gearing. Its capacity is 21 ft. diameter and, in addition to being fitted with the creeping table, it carries several important improvements both electrical and mechanical, particulars of which will be given in due course.

CATALOGUES RECEIVED

Two New Gauges by A. C. Wickman, Ltd.— Two interesting new Catalogue sheets issued by Messrs. A. C. Wickman, Ltd. (Banner Lane, Tile Hill, Coventry), describe the Venwick Gauge, and the "Eeseset" adjustable caliper gauges, respectively. The Venwick Gauge has its mechanism enclosed in a dustproof steel tube, and all working parts are made of best quality hardened steel. The scale of the gauge has 60 divisions, graduated in 0.0001, 0.00025 in., or 0.002 mm. With the Venwick Gauge the indirect measuring system is used. A Cylinder Measuring Instrument is used to check the external diameter of cylindrical work as well as test for roundness and parallelism. Fitted in a Universal Stand it is used for checking the true running of cylindrical pieces, to align such pieces or to check the parallelism of flat surfaces and edges, particularly necessary when assembling on a machine. Fitted in simple Column Stand with a flat measuring table it is used for comparative measuring of prismatic or cylindrical parts. Parallel precision gauge blocks or cylindrical gauges are used for setting.

The "Eeseset" Adjustable Caliper Gauges are available in six sizes. The frames are made of close grained, seasoned, high quality cast iron and the anvils of best quality tool steel, hardened and lapped. The main feature of these gauges is that correct setting can be obtained in approximately one minute. This is due to the backing screw being drilled and through which passes a removable rod. This rod pushes directly on to the back face of the anvil. With this arrangement it is impossible for the frame to spring and upset the setting as is experienced with ordinary gauges. Setting time is thus negligible.





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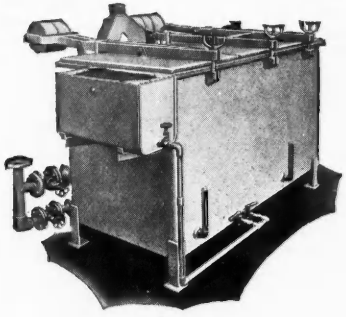

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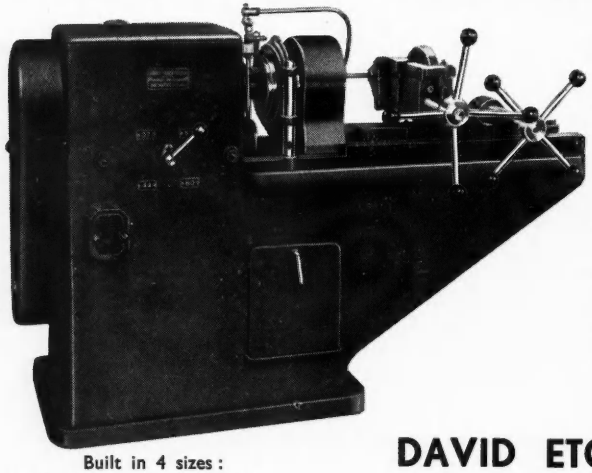
PRODUCTION THREADING MACHINES



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